OCULAR REFRACTION

AND THE

SHADOW TEST

BY

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PREFACE

This book is dedicated to the advancement of the science of optometry, and to those willing workers in the field who are ambitious for its advancement and who are laboring to that end.

The correction of errors of refraction of the eye with lenses is a noble work, involving the betterment of conditions under which mankind is enabled to enjoy the most valuable of the five senses, viz., sight.

Without glasses many would never know the beauties of our world, while others would suffer ceaseless misery.

The resources of optical science have been greatly improved, its practitioners have acquired more knowledge and skill, and its value is becoming more appreciated.

The limit of the possibilities of the work have not been reached, however, and this should stimulate individual research and study. There are rewards yet to be gained.

If this book proves to be a help to any, and stimulates new thoughts and ideas, it will not have failed in its mission. That it may be of value is the sincere wish of THE AUTHOR.

NEW YORK, June 1st, 1903.

ERRATA.

Pages 136, 137 and 138, where term "compound astigmatism" is used, read "mixed astigmatism."

By a printer's error, cut No. 44 has been inserted reversed.

On page 32 the fourteenth line should read: "bent from the perpendicular," etc.

On page 86 the fourth example of method for decentration should read:

Prism.	Dioptres.	Millimetres.
3°	6D.	$10 \times 3 = 30 \div 6 = 5$.

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CHAPTER VII.

Practical Hints for the Practice of Retinoscopy.

INTRODUCTION.

IT seems hardly possible that in this period of advanced thought and research, when almost every branch of human industry is conducted along scientific lines; that so important a profession, as that whose followers practice the adapting of lenses to correct defects of vision, has up to within a few years been guess work.

Is the term not advisedly used when an operator orders glasses for a person, taking as a basis for his calculations, the unverified statements of the person as to what he can see with this or that lens, or combination of lenses? A person may be conscientious in his replies, but may not have understood the query; again, in complicated cases, where various combinations of lenses have been tried, the ability to differentiate becomes fogged. The replies of illiterates, children and foreigners are not to be depended upon. What basis of certainty then do such methods afford; what assurance has the operator that his formula is even approximately correct?

A science is founded, not upon uncertainties, but upon facts; therefore, subjective examination of the eye is not scientific, though we grant that it has its place and should be used. It is only within the past few years, that the diagnosis of errors of refraction and their correction by the use of glasses has been scientific. Examination being conducted objectively, the refractive condition of the eye is ascertained by comparison of actual conditions with a known standard.

This work is a departure from the usual style of optical text books and is based upon methods employed by the author in successful daily practice. The subject of lenses and their properties is dealt with as fully as possible, as it is necessary in order to understand ocular refraction, to be familiar with this subject. The refractive media of the eye is equivalent to a lens.

It may be said at first glance that too much time is devoted to subjects that have little relation to optics, that the optical student need not bother with such topics. The answer is, that time spent in the study of any subject that is in any way related to optics, is time well spent. The optician must not fear to know too much but too little.

The famous address delivered by Helmholtz in 1871, at Heidelberg, shows upon what a broad basis of knowledge his intellectual

power was founded. A portion of it is quoted; the whole of it is well worth reading, it should stimulate the optical student to higher aims.

"The Mystery of Creation."—"All life and all motion on our earth, is, with few exceptions, kept up by a single force, that of the sun's rays, which bring us light and heat. They warm the air of the hot zones; this becomes lighter and ascends, while the colder air flows toward the poles. Thus is formed the great circulation of the passage-winds. Local differences of temperature over land and sea, plains and mountains, disturb the uniformity of this great motion, and produce for us the capricious change of winds. Warm aqueous vapors ascend with the warm air, become condensed into clouds, and fall in the cooler zones, and upon the snowy tops of the mountains, as rain and as snow. The water collects in brooks and rivers, moistens the plains and makes life possible; crumbles the stones, carries their fragments along, and thus works at the geological transformation of the earth's surface. It is only under the influence of the sun's rays that the variegated covering of plants of the earth grows; and while they grow, they accumulate in their structure organic matter, which partly serves the whole animal kingdom as food, and serves man more particularly as fuel. Coals and lignites, the sources of power of our steam engines, are remains of primitive plants, the ancient production of the sun's rays.

"Need we wonder if to our forefathers of the Aryan race, in India and in Persia, the sun appeared as the fittest symbol of the Diety? They were right in regarding it as the giver of all life—as the ultimate source of almost all that has happened on earth.

"But whence does the sun acquire this force? It radiates forth a more intense light than can be attained with any terrestial means. It yields as much heat as if fifteen hundred pounds of coal were burned every hour upon each square foot of its surface. Of the heat which thus issues from it, the small fraction which enters our atmosphere furnishes a great mechanical force. Every steam engine teaches us that heat can produce such force. The sun, in fact, drives on earth a kind of steam engine whose performances are far greater than those of artificially constructed machines. The circulation of water in the atmosphere raises, as has been said, the water evaporated from the warm tropical seas, to the mountain heights; it is, as it were, a water raising engine of the most magnificent kind, with whose power no artificial machine can be even distantly compared. I have previously explained the mechanical equivalent of heat. Calculated by that standard, the work which the sun produces by its radiation is equal to

the constant exertion of seven thousand horse power for each square foot of the sun's surface.

"For a long time experience had impressed on our mechanicians that a working force cannot be produced from nothing; that it can only be taken from the stores which nature possesses, which are strictly limited, and which cannot be increased at pleasure—whether it be taken from the rushing water or from the wind; whether from the layers of coal, or from men and from animals, which cannot work without the consumption of food. Modern physics has attempted to prove the universality of this experience, to show that it applies to the great whole of all natural processes, and is independent of the special interests of man. These have been generalized and comprehended in the all-ruling natural law of the conservation of force. No natural process, and no series of natural processes, can be found, however manifold may be the changes, which take place among them, by which a motive force can be continuously produced, without a corresponding consumption. Just as the human race finds on earth but a limited supply of motive forces, capable of producing work, which it can utilize but not increase, so also must this be the case in the great whole of nature. The universe has its definite store of force, which works in it under ever-varying forms; is indestructable, not to be increased, everlasting and unchangeable like nature itself."

It is the author's conviction, that the greatest success at present is being made, and in the future will be attained, by that class of operators, oculists and opticians, who make retinoscopy the corner-stone of the adapting of lenses to the correction of refractive errors. The aim of the work will, therefore, be to teach the fundamental principles of retinoscopy, to fit the student to intelligently use the retinoscope in diagnosing errors of refraction. The great difficulty with operators of the instrument is, that while they know that certain phenomena occur, they do not understand the cause of such, hence their indifferent success in its use.

The method of teaching is as far as possible objective; a law is given in as simple yet comprehensive form as possible, followed by experiments or demonstrations to prove it; the student should make these for himself.

A well known educator once said:—"It is a cardinal principle in modern pedagogy that the mind gains a real and adequate knowledge of things only in the presence of things themselves. Hence the first step in all good teaching is an appeal to the observing powers. The subject studied and the studying mind are placed in the most direct

relations with one another that circumstances admit. Words and other symbols are not allowed to intervene, tempting the learner to satisfy his mind with ideas obtained at second-hand."

The use of analogy is resorted to at times that students may find it easier to comprehend and memorize facts. The field of optical investigation is large, and each should feel that he has just as good an opportunity as another to make some valuable discovery; certainly his investigations will yield him personally good returns.

The author acknowledges assistance received from the writings of Francis Valk, M.D., of New York, Alfred P. Gage, A.M., of Boston, Prof. Ira Remsen, of Johns Hopkins University, Baltimore, and others.

That the work is complete and without fault is not claimed, but that it may be of some service in advancing the science of ocular refraction is the wish of the author.

March 8, 1902.

CHAPTER I.

LIGHT.

Energy is that which creates, destroys, or changes motion; it is power in action.

It is conclusively proved that the store of energy in the universe is constant, none can be created, none is destroyed; it is merely transformed from one form into another, each bearing a definite relation to the other; this is termed the correlation of forces and the conservation of energy. We are accustomed to think of energy as power to do work; it assumes various forms, mechanical, chemical, electrical energy, etc. While there is no loss of actual energy in transformation, there is a loss of available energy, a portion taking the form of heat expended. The steam engine transforms chemical energy stored in coal into mechanical energy; the turbine transforms energy stored in water, due to its position, into mechanical energy; the dynamo transforms mechanical into electric energy, which is transformable into light, heat and motion.

A good example of the transformability of energy, is furnished by the electric cars on our streets; they are propelled, lighted and heated from the same source.

The principal sources of energy stored upon the earth and available to the use of man, are the processes of combustion, coal, wood, oil, etc.; water in motion, and at an elevation, thus available through gravitation; air in motion The source of all energy on the earth is, with few exceptions, the rays of the sun.

That form which is manifested as heat and is termed *radiant energy*, is that which makes possible the science of optics.

Every body gives off radiant energy regardless of its temperature. It is manifested by the propagation in the ether of waves that transmit the radiant energy to other bodies, these may in turn send it

to still other bodies. These waves are of different length, those sent out by a cold body being longer than those of a hot. In the lower temperatures the waves are of such length that they make no impression upon the eye, and we recognize them merely as heat. At about 1080° Fahrenheit a body radiates energy that causes it to emit a red glow, and is said to be luminous, radiating rays of red light. As the temperature becomes higher, the waves are shorter and shorter, and the various colors of the spectrum in regular order are radiated, until

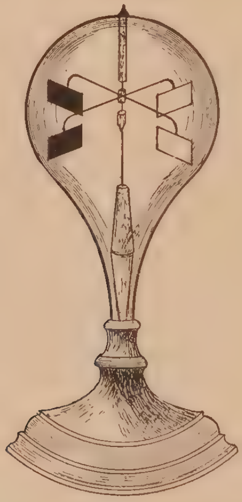

Figure 1.
The Radiometer.

at about 2700° Fahrenheit, all the colors of the spectrum are radiated and the body is said to be white hot. When in this condition, the radiant energy given off by a body is called *light*.

The eye is adapted to perception of waves of certain lengths, they are those that produce the colors of the spectrum; red, orange, yellow, green, blue and violet; those having greater and less length than these, do not affect the eye, therefore, in the study of ocular refraction we need not consider them. The effect these waves produce upon the eye is called *sight*. The velocity of light is about 186,000 miles in a

second; thus it is easy to understand how we can so quickly see any object, no matter what its distance, as soon as we direct our eyes toward it; the light it sends to the eyes traverses the intervening space in an inconceivably small fraction of time. An illustration of the rapidity with which light travels, as compared to that of sound, is seen by the puff of steam from the whistle of a distant locomotive, followed by the sound some time later; and the flash of a gun and its report. Sound waves traverse the air at the rate of but 1,100 feet in a second.

Light is that part of radiant energy, by means of which, through its action upon the eye, we are enabled to see the object from which it proceeds. That light is a form of energy, and as such can produce motion, is illustrated by an instrument called the radiometer; (Fig. 1.) It consists of two crossed arms in the shape of a vane, at the extremity of each of the arms is a small disk of aluminum, blackened on one side, white on the reverse. This vane is delicately poised and is rotatable on a pivot, is inclosed in a glass bulb from which the air has been exhausted. Exposed to the light, the vane revolves, the white faces of the disks in advance; the stronger the light the more rapid the motion of the vane. Motion is created where energy is applied, therefore, energy must be exerted upon the vane in a certain way. Now, as energy must have some medium through which to act, something must remain inside the bulb after the air is exhausted.

It is now generally accepted as a fact that there exists in all space a certain medium, to which has been given the name *Ether*; that it penetrates everywhere, that radiant energy causes it to vibrate and imparts to it a wave-like motion, that to certain of these waves, the eye is sensitive. This is the *wave or undulation theory of light.*

It is only by assuming the existence of some medium capable of transmitting light between objects, much in the same way that air transmits sound, that we can account for the actions of light. Some thing cannot be evolved from nothing, neither can space that contains nothing communicate sound or light between distant points. This ether is, therefore, assumed to fill all space, penetrating all liquids and solids, and surrounding every molecule of matter in the universe, just as the air envelops the earth. The air surrounding the earth is comparatively a thin belt, so that ether fills the interplanetary space. This theory of the existence of ether links light and sound intimately, each acting through a medium by the propagation of waves, and in the study of light the student will find it helpful to an understanding of the various phenomena if he has some knowledge of sound. As air

and sound are more tangible than ether and light he may use the analogy for study purposes.

We are compelled to accept certain things as facts, reasoning upon a basis of cause and effect, thus: We do not know that a dumb animal can see and hear, but we accept it as a fact, because it acts as if it does, for upon no other basis can we explain certain of its actions. Following this line of reasoning we can safely accept the theory of the existence of ether until it is disproved.

Light itself is invisible, but objects within its path are rendered visible by the light they reflect.

Darken a room and admit the sunlight through a small round hole, the light is not visible, but its path is easily traced by the dust particles floating in the air and crossing its path are illuminated. Where the light strikes the floor or wall a small round spot will be seen, due to its illumination, but the room remains dark. If there were no such dust particles or other objects in the room to obstruct its path it could not be traced, but only the point where it strikes would be seen. The path the light traverses in the room will be found to be straight.

Light always travels in a straight line.

Take a cigar box, and having removed one end, replace it with ground glass, L M N O (Fig. 2), make a small round hole A exactly in the centre of the other end. On the bottom glue at intervals small

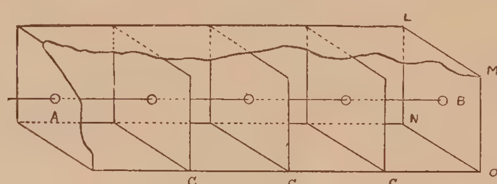

Figure 2.
Device to prove that the path of light is straight.

strips of wood in pairs, spaced close enough to hold a card, parallel to the ground glass. Cut several cards to just fit inside the box in these slots, in the centre exactly of each make a hole the size of the one in the box at A. Place three or more of these cards C in the slots made to hold them. Darken a room and place a lighted candle in the centre of it; from any position in the room, by directing the aperture in the box toward the candle, a spot of light will appear in the centre

of the ground glass. As the holes in the cards and the front of the box are in line, the path of the light through the box must be straight.

Substitute for one of the cards now in the box one in which the hole is not in the centre; no light will now appear upon the glass.

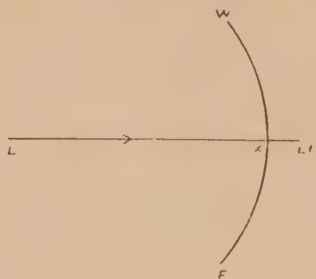

Figure 3.

Diagram to illustrate the propagation of a light ray, L L.

This not only proves that light travels in a straight line, but also that it cannot deviate from it.

A ray is the smallest conceivable amount of light; it is propagated along a line that is perpendicular to the wave front at the point of intersection.

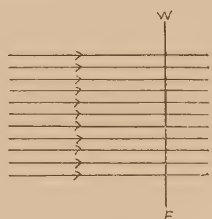

Figure 4.

Formation of a beam of light.

Figure 3 represents a line L L′ perpendicular to the wave W F; at the point of intersection X, it indicates the path of a light ray from L to L′.

A beam is a collection of rays whose paths are parallel.

Figure 4 represents parallel rays intersecting the wave W F perpendicularly; it is seen that this can occur only where the surface of the wave is a plane at the points of intersection.

A pencil is a collection of rays whose paths meet at a common point.

Figure 5 represents rays cutting the wave W F perpendicularly at the points of intersection. As the surface of the wave is not a plane the rays cannot be parallel, and if prolonged must, therefore, meet at some point, which we will assume to be at P.

Light makes objects visible, some by means of that which they create, as a candle flame, electric light, the sun, etc.; these are

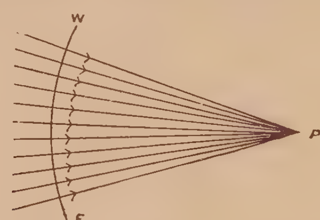

Figure 5.
Formation of a pencil of light.

termed luminous bodies. Other bodies are rendered visible when they receive light from luminous bodies, in which state they are said to be illuminated, as trees, houses, etc.

Luminous bodies emit light in all directions equally and from every point of their surface.

Take a tin can and punch holes around it with a small round wire nail, place a lighted candle inside and take it into a darkened room. It will be observed that light is emitted from all the holes alike. By looking through any of the holes various points of the candle flame will be seen, showing that every point is an independent source of light; this makes possible the formation of images. The experiment illustrated by figure 2 also demonstrates this.

Rays of light given off by luminous and illuminated objects are divergent, never convergent, unless rendered so by some applied condition, and are only theoretically parallel when they come from a distance of twenty or more feet.

Figure 6 represents a candle L and rays of light radiating from it in all directions showing their divergency. The angle N L O, made by the rays N and O, is less than the angle M L P, made by the rays M and P, and the smaller the angle formed by two straight lines the nearer they approach being parallel; therefore, the rays N O are nearer parallel than M P, but M P are more divergent than N O, and R P are still more divergent than M P. This diagram illustrates why no two rays from the same point can be parallel. Place a card per-

pendicular to the base line upon which the candle is fixed, cutting the rays M N O P at A B C D. Suppose the distance from B, where the ray N strikes the card, to C, where the ray O strikes, is one quarter of an inch, and a hole one quarter of an inch in diameter be made in the card, all the rays included between N and O will pass through the hole. In order to permit the rays M and P to pass through the same

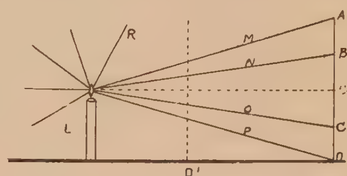

Figure 6.

Radiation of light in all directions; divergency of the rays.

hole, by reason of their greater divergency, it would be necessary to move the card nearer to the light, to say D′, this would allow rays included between M and P to pass through. This experiment demonstrates two facts, viz.: that rays of light passing through a given aperture are more divergent as it approaches their source, that the number of rays (or the amount of light) passing through a given aperture decreases as it is removed from their source.

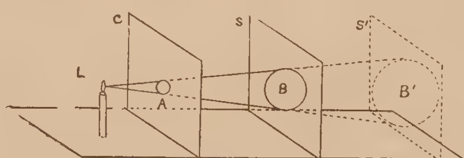

Figure 7.

Variations of intensity of light at different distances from its source.

The intensity of light decreases as the square of the distance traversed increases, thus, at twice the distance, one-fourth the intensity; four times the distance, one-sixteenth its intensity.

Figure 7 represents a candle L placed before a heavy piece of cardboard C, having a small round hole at A; the screen of white paper S held back of C, say two inches, so that light passing through

A will fall upon S and make a round spot of light B. Move S four inches away from C to the position S′ and note the size of the spot B′ If S was two inches from C and the diameter of B was three inches, then if S′ be placed four inches from C the diameter of B′ will be six inches, just twice the diameter of B. Now, as the areas of any two circles are to each other as the squares of their diameters, the area of B′ is four times that of B, and as each receives the same amount of light, for the positions of L and C remain the same, the intensity of the light at B′ is only one-fourth that at B. In the experiment made with the apparatus illustrated by figure 2 it will be found that the nearer the light is approached, the brighter the light upon the ground glass will appear, the further it is removed the fainter the spot will be.

Light exhibits certain phenomena; it is absorbed, transmitted, reflected, diffused, refracted, etc.

The effect of the absorption of certain light rays is to give an object color; those that it rejects or sends to the eye produce the effect of red, green, blue, etc. Objects that absorb none of the light rays, but send all combined to the eye have the appearance we term white; those that absorb all the rays, returning none to the eye, appear black, as it is called. The term blackness or darkness means an absence of light, and all objects are black in the dark. An object to appear of a certain color must receive light of that color, if it does not receive such its color is changed; if the proper color of light combined with other light colors are received, those for which it is not adapted are absorbed. The absorption of rays of light warms an object, as it converts them into heat, thus: Of two objects receiving the same light that which absorbs the most light rays will be the warmer, while that absorbing the lesser number of rays will be the cooler. This explains why people living in tropical countries adopt white for clothing; it is cooler because it absorbs little light energy.

Rays of light striking the surface of a medium, some of them pass through it or are *transmitted.* Different bodies offer more or less obstruction to the passage of light rays; those that offer little, such as air, glass, water, crystal, etc., are termed transparent; those that permit but a portion of the light rays to pass through, such as thin paper, ground glass, etc., are termed translucent; those that do not permit the passage of any of the light rays, such as heavy paper, sheet tin, etc., are termed opaque. The terms transparent and opaque are not absolute, for all substances offer some obstruction to the passage of light, while none completely obstruct it. Even air does not transmit

all rays of light from a given source, and iron rolled thin enough transmits an appreciable amount of light.

The rays of light that are not transmitted on striking the surface of a medium are bent back into the medium through which they came, they are said to be *reflected*. The rays approaching and striking the surface of a medium are called the *incident rays*; those that are bent back into the medium whence they came are called the *reflected rays*.

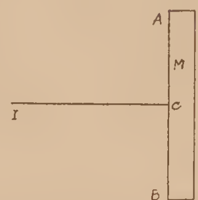

Figure 8.
Perpendicular reflection of light ; I C, incident ray ; C I, reflected ray.

Light rays striking the surface of a medium perpendicularly and reflected, traverse the same path by which they approached; they are, therefore, reflected to their source.

Figure 8 represents a medium M, the incident ray I strikes the surface A B at C; I C is perpendicular to A B, and the path of the incident ray is from I to C in a straight line, that of the reflected ray is also in a straight line from C to I, or back to its source.

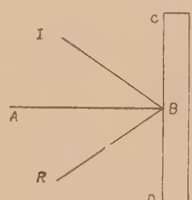

Figure 9.
Oblique reflection ; I B, incident ray ; B R, reflected ray.

Light rays striking the surface of a medium in any direction other than perpendicular to its surface at the point of incidence and reflected, the incident rays form an angle with the perpendicular which is called the angle of incidence. The reflected rays form an angle also with

the perpendicular called the angle of reflection. *The angle of incidence and the angle of reflection are always equal.*

In figure 9, I is the incident ray striking the surface C D at B and reflected to R; A B is the perpendicular to C D at B. The angle of incidence I B A is equal to the angle of reflection R B A. To find the direction that a reflected ray will take it is only necessary to erect at the point of incidence a perpendicular, ascertain the angle of incidence and construct the angle of reflection equal to it.

Into a darkened room admit a pencil of light through a small hole, place a mirror so as to receive it obliquely upon its surface. The light is reflected, according to the law of reflection, in a given direction, and by placing the eye in the path of the reflected pencil an image of the source of the light is seen upon the mirror, and not the mirror. If the mirror be covered with a piece of white cardboard, the source of the light cannot be seen; though the incident pencil follows the same certain direction as before, some change takes place at the point of incidence, the reflected pencil does not follow any definite direction, it is broken up, and the various rays are reflected in all directions. This

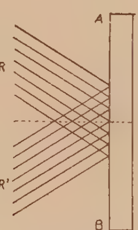

Figure 10.

Reflection by a mirror ; formation of the image.

renders the cardboard visible from any position in the room. The phenomon is due to the difference in the reflecting surfaces. A smooth surface reflects light in a definite direction, creates an image of the object from which the rays proceed, and is called a mirror. A rough surface scatters the light, illuminates adjacent objects, and does not create an image. The best mirrors are polished metal surfaces and smooth glass backed with an opaque substance.

The pencil of light composed of the rays R, figure 10, strikes the surface of the mirror A B, and is reflected in a definite direction R'. This is due to the fact that all points in the surface A B lie in the same plane. An image is created by the surface A B.

The amount of light that a smooth surface reflects increases with the angle of incidence.

A B, figure 11, represents a plane mirror in a horizontal position, above it is placed the goblet L. Looking from the position E at the goblet reflected in the mirror, it appears to be inverted and situated at L′. Every point upon the goblet sends out light which is reflected to the eye. Let C F and D G represent divergent rays of light from the points C and D; erect perpendiculars P P to the surface A B at the points of incidence F and G. By constructing the angles of incidence

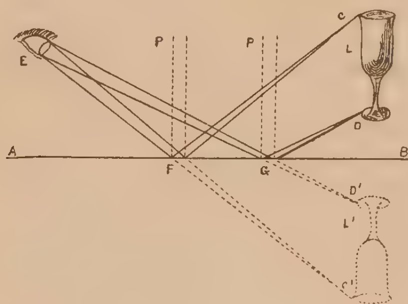

Figure 11.

Inversion of the image by reflection of a horizontal plane mirror.

and reflection, the paths of F E and G E are found. By this it is shown that divergent rays reflected by a plane mirror continue divergent after reflection; in the same manner it can be demonstrated that parallel and convergent rays reflected by a plane mirror continue parallel or convergent after reflection. Figure 10 shows that parallel rays reflected by a plane mirror are parallel after reflection. To the eye the position of an object appears to be in the direction from which the rays of light enter the eye. By prolonging the lines E F and E G they will meet at the points C′ and D′, showing why L appears to be placed at L′ and why inverted. This is called a virtual image of an object because it is not a real image. A virtual image formed by a plane mirror is a reproduction in size and shape of the object reflected, and is the same distance behind the mirror as the object is in front of it. This fact is frequently utilized to reflect a test chart placed at the back of a person in the operating room. The chart must be printed in reverse.

The mirror doubles its distance, as the eye, instead of receiving incident rays from the chart, receives reflected rays; the light traversing the space between the chart and the mirror and back again to the eye of the patient.

Objects reflected by a horizontal plane mirror are inverted, thus: Trees on the banks of a stream or lake reflected by the surface of the water appear to be growing downward into the water. Objects reflected by a vertical plane mirror are reversed, thus: In looking into such a mirror one's right hand appears to be the left. When a plane mirror is tipped away from a vertical or horizontal plane, objects reflected by it form an angle with the horizon that is dependent upon the angle of the mirror.

Let A B, figure 12, represent a piece of thick plate glass mirror; L, a pencil of light striking the surface obliquely at C, is reflected to D; all the light, however, is not reflected at C, a portion of it is transmitted by the glass to K, from K it is reflected to E, and a portion

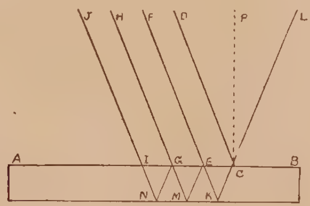

Figure 12.

Principle of multiple reflection.

continues to F; that which does not pass from the glass at E is reflected to M and thence to G, a portion continuing to H; that which does not pass from the glass at G is reflected to N, thence to I, and a part continues to J, etc. This continues until the light can no longer be perceived as the intensity is reduced at each reflection. An image is created by the points of reflection C K E M G N I. The further away from the first point of reflection the fainter the image becomes. As E and K are in the same plane the images they create are seen as one, being superimposed, the same is true of G M and I N. The above phenomena is termed *multiple reflection*, and shows that even glass does not transmit all the light that strikes it, but reflects a portion.

Hold a lighted candle near a thick glass mirror, look at its image reflected in the mirror in a line perpendicular to the surface of the mirror, but one image will be seen with a faint ghost of another back of it. Now move to a position so that the visual line strikes the surface of the mirror obliquely and several images of the flame will appear. The more oblique the angle the greater number of images will be seen. The reflections from the surfaces of glass account for the annoying phenomena that glass wearers sometimes complain of when they first attempt to wear them.

Figure 13 represents a sphere S, the centre of which is at C. Any straight line drawn from C to the circumference will be a radius of the sphere and therefore a perpendicular to the circumference at the point of incidence. Let A B represent a concave mirror; being a

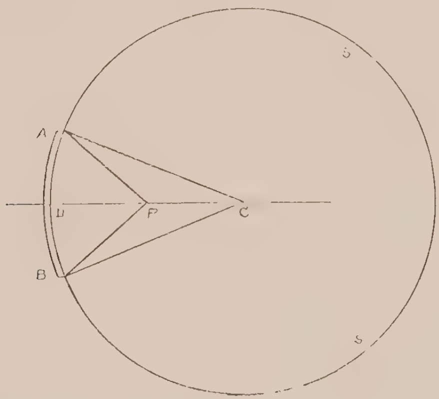

Figure 13.

A concave mirror is a section of a sphere. The aperture A B; centre of curvature, C; vertex, D; radius, A C; principle axis, D C; focus, P; focal length, D P.

section of S its *centre of curvature* will be at C, the geometric centre of the sphere. A point D, located half way between A and B upon the surface of the mirror, is called the *vertex* of the mirror, and a straight line drawn through the centre of curvature and the vertex indicates the *principle axis* of the mirror. The *aperture* of the mirror is the distance between A and B.

If light be placed at the centre of a concave mirror, it will be reflected from all points upon the surface of the mirror back to its

source; the path of each ray will be a radius of the mirror and will be perpendicular to the small plane at the point of incidence; thus, the incident and reflected rays traverse the same path. Any ray passing through the centre of curvature of a concave mirror and incident at any point upon the mirror other than the vertex. is reflected to its source and its path is said to be a *secondary axis* of the mirror.

Figure 14 represents a concave mirror A B; from the points E and F located at equal distances from the vertex upon A B, draw the radii and locate the centre C and the principle axis D C. Suppose parallel rays strike the mirror, one ray traversing the principle axis, the ray R, incident at E, and S at F, form the angles of incidence R E C and S F C; constructing the angles of reflection C E P and C F P, it is found that the reflected rays meet at a point P on the principle axis

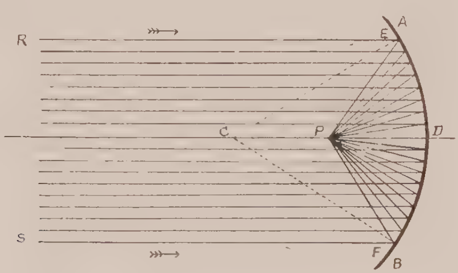

Figure 14.

Reflection of parallel rays by a concave mirror; also, reflection of light situated at the focus of a concave mirror.

which is called the *principle focus* of the mirror; it is located half way between the centre of curvature and the vertex. By this it is proved that *any ray from an object, parallel to the principle axis of a concave mirror, by reflection passes through the principle focus.* The distance between the vertex and the principle focus is the measure of the *focal length* of the mirror. A concave mirror renders parallel rays convergent, and light situated at the focal point is projected parallel by reflection. *The focus then is a point at which light rays that diverge from one point meet again after reflection.*

Figure 15 represents a concave mirror A B; the light (radiant point) is situated at the point G upon the principle axis which is beyond the centre of curvature C; from the points E and F located upon A B, equally distant from the vertex D, construct the angle of inci-

dence G E C and G F C, for the rays G E and G F, and the angles of reflection C E H and C F H. The rays will be found to focus at H; by the same construction, if the light were situated at H the rays would be brought to a focus at G. The points G and H thus bear a definite relation to each other. Light situated at either is reflected to the other and these points are called *conjugate foci.* The conjugate foci of rays reflected from an object by a concave mirror, are upon the same side of the mirror, when the object is situated beyond the focus; either may be taken as the location of the radiant point and their positions are reversible.

Concave mirrors reduce the divergency and increase the convergence of incident rays. The images created by concave mirrors vary with the position of the object reflected.

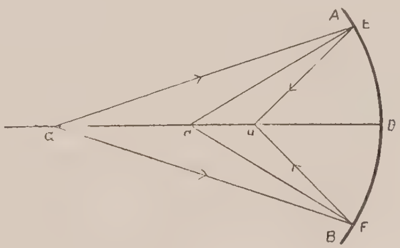

Figure 15.

Reflection of divergent rays by a concave mirror. Conjugate foci, G and H; radiant point, G.

If the object be situated beyond the centre of curvature, the image is real, smaller than the object, inverted, and located between the principle focus and the centre of curvature.

If the object be situated between the principle focus and the centre of curvature, the image is real, magnified, inverted, and located beyond the centre of curvature.

If the object be situated between the principle focus and the mirror, the image is virtual, not inverted, magnified, and located behind the mirror.

If the object be situated exactly at the centre of curvature no image is formed, as the object and the image are located at the same point.

Take a bright new spoon and using the bowl as a concave mirror, reflect a pin in it; with the pin in contact with the surface it appears erect and slightly magnified, withdraw it slowly, the image remains erect and the magnification increases until the image blurs and finally disappears. This indicates that the pin is located at the centre of cur-

vature of the bowl of the spoon. Withdrawn still further from the surface of the bowl, the image reappears but is inverted and smaller than the pin.

Figure 16 represents a convex mirror A B; its centre of curvature is at C which is behind the surface of reflection. Rays from G to E, and from G to F are reflected to L and M; C H and C K are perpendiculars to A B at the points of incidence E and F; G E H and G F K are the angles of incidence, L E H and M F K the angles of reflection; hence, E L and F M indicate the paths of G E and G F after reflection.

Convex mirrors increase the divergence of incident rays, render parallel incident rays divergent, and reduce the convergence of incident rays; they may reflect convergent rays as parallel or even divergent.

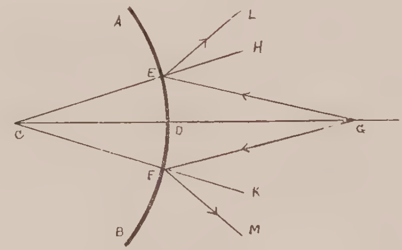

Figure 16.
Reflection by a convex mirror, the centre, C; vertex, D; principle axis, C. D.

The image formed by a convex mirror is smaller than the object, is erect, virtual and situated behind the mirror.

An image of anything is a copy, reproduction or counterpart of it. *An optical image is an appearance of an object created by the projection of a single ray from every point upon an object through an infinitely small aperture upon a screen; also created by the reflection of incident rays upon a mirror from every point upon the object, or their refraction by some medium.*

There are two kinds of optical images, real and virtual; a *real image* is one that can be received upon a screen; it is created when the conjugate foci of rays are upon the same side of a mirror, also created by rays passing through an aperture A *virtual image* is one that cannot be projected and received upon a screen, but reaches the eye by reflection and the rays form a real image upon the retina.

The formation of images by a lens will be taken up under the subject of lenses.

Figure 17 represents a lighted candle placed before a thin opaque plate P of say, tin, having a very small aperture at A A; the screen of white cardboard I is placed back of the plate to receive the image. Rays R from all points of the candle meet the plate P and are intercepted by it, only those reaching A A pass through and are received by the screen I; if A A were small enough only one ray from each point would reach I. As the paths of the rays are straight, a ray from each of the points A, B and C reach the screen at the points A′, B′ and C′; the same is true of all rays forming the image and this shows why the images formed by apertures are inverted. If the distance of the screen from the aperture is equal to the distance of the candle from the aperture, the image will be the same size as the candle; if further away, say at I′, the image A″ B″ C″ will be larger than the object; the nearer the screen is brought to the aperture the smaller and brighter will be the image. If the aperture is made through a thick plate the image formed will be poor. To obtain a clear cut image it

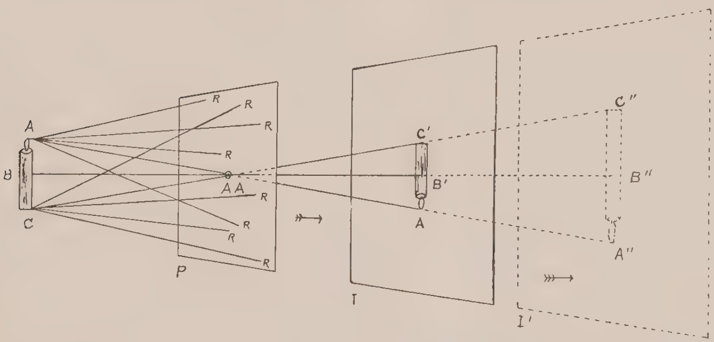

Figure 17.
Formation of image by an aperture.

is necessary to have the smallest possible aperture in the thinnest possible plate. A camera can be constructed upon this principle and photographs made without the use of a lens, which in point of detail are superior to those made with a lens. The greatest drawback to such pictures is the time required for the exposure due to the small amount of the light projected upon the plate. Any number of aper-

tures can be used in the experiment illustrated by figure 17, and each will create an image which will be distinct so long as it is not overlapped by the image from another aperture; when the apertures are so close together that the images they create overlap, the result is illumination and no formation of distinct images.

Figure 18 represents a plane mirror A B, to the eye placed at E the image of the candle C appears by reflection at C′, which is the same size and shape, in other words, an identical reproduction of C, and located behind the mirror the same distance that the candle is in front of it.

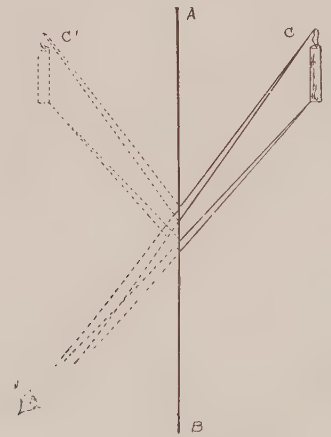

Figure 18.

Formation of virtual image by a plane mirror.

To locate the position of an image created by a concave mirror let figure 19 represent a concave mirror A B; its centre of curvature at C; the principle focus at P; the object being located at L M, beyond the centre of curvature. Draw the principle axis C D and parallel to it draw the incident ray L E, which is reflected through the principle focus; another ray from the same point L through the centre of curvature is incident at H and on reflection meets the reflected ray E P at L′; this is the conjugate foci of all rays from the point L and at L′ is formed the image of this point. In the same way locate the image of M at M′ and the points between L and M will be imaged between

L′ and M′. This diagram may be reversed to show L′ M′ as the object and L M as the image. In either case the images are real, being formed by rays that actually meet after reflection.

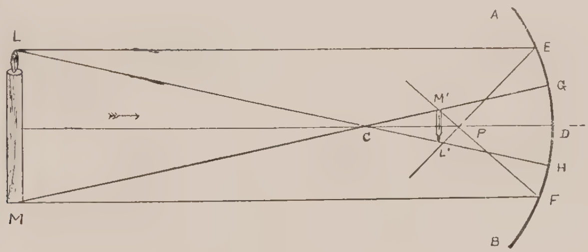

Figure 19.

Formation of real image by a concave mirror, the object being situated beyond the centre of curvature. The object, L M; image, L′ M′; centre of curvature, C; principle focus, P; secondary axes, L H and M G.

Figure 20 represents an object L M so placed with regard to the mirror that no ray passes from it along the principle axis. To locate the image in such cases draw the path of a ray from the point L parallel to the principle axis and incident at F, from F it is reflected

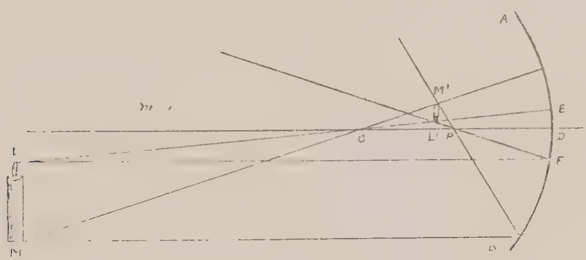

Figure 20.

Position of image of object placed to one side of the principle axis.

through the principle focus; another ray from the same point L forming a secondary axis L E. The conjugate foci of E L and F P locates the image of the point L at L′; in the same manner locate the image of M at M′, etc. When the object lies wholly to one side of the principle axis the image is upon the other.

In figure 21 the object L M is situated between the principle focus P and the vertex D An incident ray L E parallel to the principle axis C D is reflected through the principle focus P; a secondary axis C L meets A B at G and a ray from L to G is reflected through C; the reflected rays G C and E P are divergent and, therefore, cannot meet; they have but a virtual focus which is located by extending them back of the mirror where they meet at the point L′; the point M′ is found in the same way, and L′ M′ represents the virtual image of L M.

Figure 22 shows at a glance the characteristics of images formed of objects in different positions with regard to a concave mirror; the dotted lines connect each object and its image. The image of L is

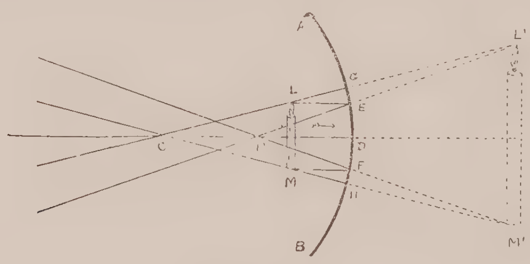

Figure 21.

Formation of virtual image by a concave mirror, object between principle focus and mirror. The object, L M; image L M′; principle focus, P.

at L′, is inverted, real and magnified; the image of L′ is at L, is inverted, real and smaller, the image of N is at N′, is erect, virtual and slightly magnified; while the image of M is at M′, is erect, virtual and greatly magnified. The centre of curvature is represented at C, the principal focus at P, and the mirror at A B.

Figure 23 illustrates the formation of the image by a convex mirror. The object is at L M, the mirror is A B. To locate the image of the point L, draw the path of a ray from L through C; another from L parallel to C D, construct the angles of incidence L F F′ and the angle of reflection K F F′; by extending K F back of the mirror as a straight line, it meets L C at L′. Another ray from L to E is reflected to H, L E E′ being equal to H E E′; extending H E back of the mirror as a straight line it also passes through L′, which is, therefore, the virtual focus for all rays from the point L. In the same manner locate the focus of M at M′; thus, L′ M′ is the virtual

image of L M. By reversal, figure 21 shows the construction of the image created by a convex mirror taking L′ M′ as the object, L M will be the image.

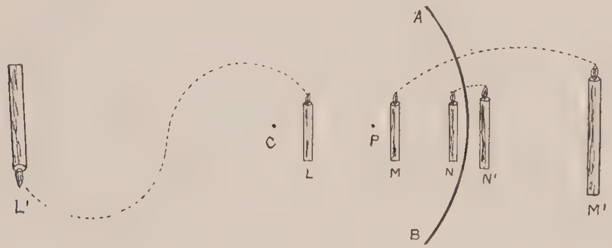

Figure 22.

Diagram showing kind and position of images formed by concave mirror, object in various positions. Dotted lines join object and its image.

Considerable space has been devoted to the subject of reflection by mirrors and this indicates its importance.

The student is urged not to pass beyond this subject until he has thoroughly mastered it, practising the formation of images by dia-

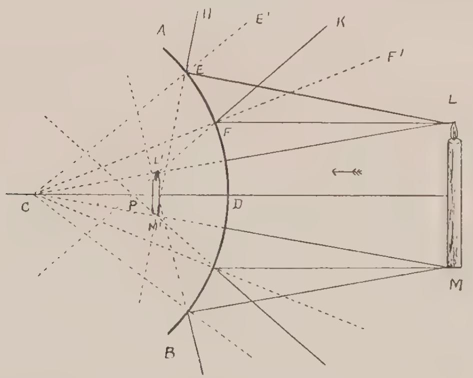

Figure 23.

Formation of virtual image by convex mirror. The object L M; image L′ M′; centre of curvature, C; virtual focus, P.

grams drawn by himself; no matter how poor a draughtsman he may be, the practice will be valuable. The subject may seem com-

plicated at first, but there are only a few important points to understand, and it becomes easy.

As the retinoscope is but a plane, or concave mirror, by which light is reflected into the eye, causing certain phenomena by which the refraction of the eye is estimated, it can readily be appreciated that the laws of reflection by mirrors should be thoroughly understood.

Mirrors are surfaces that reflect light in definite directions, as we have seen, but every body reflects light; rays that are incident upon a surface, that is irregular, are not regularly reflected, but are reflected in all directions or scattered. Under such conditions light is said to be *diffused* and no image is created by the reflecting surface.

The beam of light composed of the rays R, figure 24, approach the surface of C D in a definite direction and are reflected; as the surface C D is irregular or roughened, all its points do not lie in the same plane and the angles of incidence must vary for each ray;

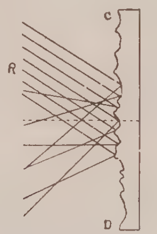

Figure 24.
Diffusion of light by reflection,

the angles of reflection are also different and the reflected rays are scattered in all directions creating *diffused light*.

It is by diffused light that most objects that we see are rendered visible. They are said to be illuminated and may be seen from any direction, as they receive and reflect light from all directions.

Incident rays upon the surface bounding two media of different density are divided at the surface, a portion we know is reflected, the remainder is transmitted; the manner of transmission varies and is dependent upon given conditions. There are certain laws with regard to the incident and reflected rays that are similar to those governing the transmitted ray and this simplifies the study. The path of the incident ray that is perpendicular forms a straight line with the path of the reflected ray; so, too, the path of the incident ray that is

perpendicular forms a straight line with the path of the transmitted ray. The incident ray that is not perpendicular forms an angle with the perpendicular and also with the transmitted ray; this is the foundation for the following law:

The path of light rays passing obliquely from one medium to another of different density is broken at the surface bounding the media; this is termed the refraction of light.

If the path of rays passing from one medium to another of different density strikes the surface bounding the media perpendicularly, they arc not refracted; the path of the rays in the second medium will be a continuation in a straight line of their path in the first. If they are not perpendicular they are refracted and the paths in the first and

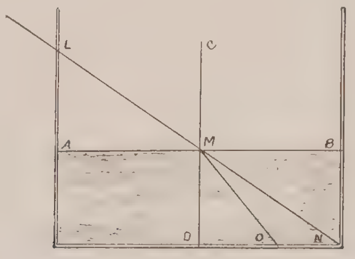

Figure 25.

Refraction. Incident ray, L; incident point, M; bounding surface, A B; perpendicular, C D; refracted ray, M O.

second media will not be a straight line, for they will form an angle whose vertex is at the bounding surface; *refraction then is a breaking of the path of the light ray.*

Figure 25 represents a ray of light from L passing through a small aperture in the side of a vessel and incident at M upon the surface A B of the water, C D is the perpendicular to A B at the point of incidence M. It will be found that M O will represent the path of the light through the water instead of M N, the original direction of L being changed at M. This indicates the point of refraction for the rays from L upon the surface of the water. If the radiant point were situated at C and rays followed the path C M, they would be transmitted to the point D; the path of the incident rays C M and that of the transmitted rays M D would thus form an unbroken straight line, for C M is perpendicular to A B, while L M is not.

The same rays will be refracted as often as they may meet another medium of different density, according to the law of refraction; this fact is made use of in various ways to correct certain faults of refractive media which will be explained later on.

Let figure 26 represent a vessel partly filled with water, A B indicating the surface. The ray from L passes to M and undergoes refraction through the water to O instead of continuing on to N. A′ B′ indicates the surface of a block of glass G upon the bottom of the vessel. As the density of glass and water is different M O undergoes further refraction at O and strikes the bottom of the vessel at O′ instead of at P. If the path of the ray were C M, it would meet A′ B′ at D, and if A′ B′ were parallel to A B, M D would pass to E and the points C M D E would be found to be in the same line.

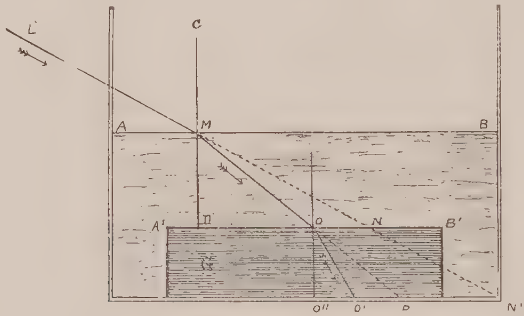

Figure 26.

Refraction of ray L at surface A B and again at A′ B′.

A pencil placed obliquely in a glass of water appears broken where it enters the water; an oar placed over the side of a boat into the stream appears to be bent at the surface; the part immersed appears shortened and bent upward. One of the effects of refraction is to create a false idea of depth; objects upon the bottom of a clear stream appear much nearer t e surface than they actually are, because the water is of greater depth than it appears to be; the rays of light reaching the eye from the objects upon the bottom undergo refraction at the surface of the water on emerging into the air.

The direction of the light rays from the point of refraction, through the second medium is in a straight line, conforming to the law that light always travels in a straight line. It is true that the direction of the ray is changed by refraction, but it is due to a sharply

defined break at the point of incidence; after refraction its path is again in a straight line. In defining refraction the term *breaking* is used rather than *bending* as it does not convey the idea of a curve.

It is well known that a person can run faster on land than if they attempt to run in water up to their waist. The water is of greater density than the air and impedes one's progress. The light waves experience a similar impediment to their progress, which is retarded if they pass from a rare to a dense medium; accelerated if they pass from a dense into a rare medium.

Refraction is due to the fact that the velocity of light is less in a dense than in a rare medium

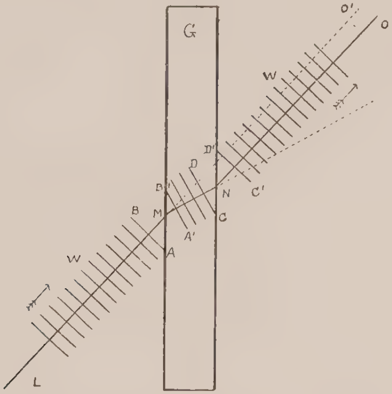

Figure 27.
Diagram showing how refraction occurs. Radiant point L.

Figure 27 explains how refraction occurs; G represents a piece of glass whose sides are parallel; the source of illumination is L. From L the light proceeds to M along the line L M, the front of the light wave is always perpendicular to the line of propagation at the point of intersection, and we can represent the light waves by a series of parallel lines W at right angles to L M. Passing through the air from L to M every portion of the wave moves with equal velocity, the density of the air being uniform. On approaching the glass the point A of each wave enters the glass before the point B; owing to the greater density of the glass than air the progress of A is retarded while that of B is not, and while the point A moves to A′, B moves to

B′ in the same time. This gives a new direction to the waves, and as the line of propagation is at right angles to the waves, by drawing a line from the point of incidence M, perpendicular to the parallel lines A′ B′, the direction the rays will take through the glass will be obtained The point where the rays meet the second surface of the glass will be located at N. On emerging from the glass at N the point C of each wave leaves the glass before the point D, and air being less dense the velocity of C is increased while that of D is unchanged; hence, in the same time that D moves to D′, C moves to C′. Another change of direction is given to the wave at the point of emergence N, and to find the new direction the wave will take from the point N, draw a line perpendicular to the lines C′ D′, which will indicate the path of the emergent rays from N to O. When a file of soldiers make a turn from their line of march they "execute a wheel'

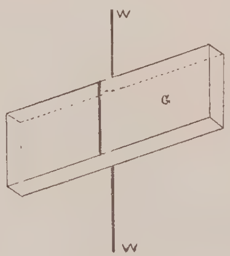

Figure 28.
Refraction by glass with parallel surfaces.

in order to keep their alignment, those upon the pivotal end marking time while those upon the other end quicken their pace; this is similar to what occurs to the light rays upon refraction, they execute a kind of wheel at the point of incidence.

The surfaces of the glass, figure 27, are parallel planes, and the lines N O and L M, indicating the paths of the light as it enters and leaves the glass, are parallel.

Figure 28 represents a thick strip of plate glass held horizontally across a paper upon which a perpendicular black line W is drawn; when the line is viewed obliquely through the glass, it appears broken at the edges of the glass; that portion seen through the glass is displaced to one side or the other as the glass is inclined toward the surface of the paper; if the glass is held so that its surface is parallel to

the plane of the paper, and the eye be placed so that the line of vision is perpendicular to the surfaces, the line drawn upon the paper will not be broken.

The incident ray that is not refracted must be perpendicular to the surfaces of the medium and they must, therefore, be parallel to each other.

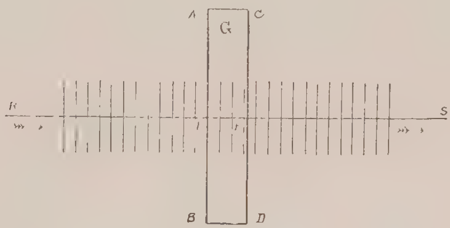

Figure 29.

Diagram showing that refraction does not always occur.

Figure 29 explains how light can be transmitted wthout refraction. The surfaces A B and C D of the glass G are parallel, the incident ray R is perpendicular at the point E; as the waves are pierced at right angles by the line of propagation they must be parallel to A B and C D. Upon approaching the glass all points on the wave

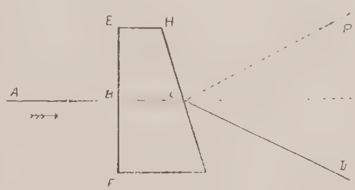

Figure 30.

Refraction always occurs when the surfaces of the medium are not parallel

enter the glass at the same time and are equally retarded, so that the direction of the wave is unchanged; leaving the glass all points emerge at the same time and are equally accelerated, so that there is no refraction and the path from R to S is a straight line.

Light is always refracted when transmitted by a medium whose bounding surfaces are not parallel; no matter what the angle of incidence the ray cannot be perpendicular to both surfaces and must be refracted by at least one,

Figure 30 represents a piece of glass whose surfaces E F and H K are not parallel. The incident ray from A is perpendicular to E F at B and passes to C without refraction; at C it is not perpendicular to H K and undergoes refraction. Some rays not perpendicular to E F may also meet H K obliquely and will be refracted by both surfaces.

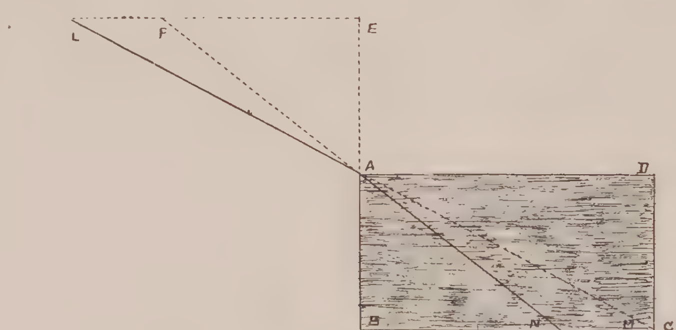

Figure 31.
Diagram to show direction the refracted ray will take.

Light passing from a rare into a dense medium and refracted, is bent toward the perpendicular drawn from the point of incidence into the secend medium; from a dense into a rare medium and refracted is bent toward the perpendicular drawn from the point of incidence into the second medium.

In figure 31 A B C D represents a rectangular vessel so placed in a darkened room that a ray of light that is admitted through a small aperture, falls in the direction indicated by the line L A, over the edge of the vessel; it will thus strike the bottom obliquely, its path being L A M. Now, without moving the vessel, fill it with water so that the surface will be indicated by A D; the light will now strike at a point between M and B which we will indicate as N, showing that its path is now L A N. On entering the denser medium, water, it is refracted toward the perpendicular drawn from the point of incidence A into the water, which will be A B. Empty the vessel of

the water and place it in its former position; admit ample light to the room, and if a card perforated with a small round hole be placed at L, on looking through this hole in the direction L A the point M on the bottom of the vessel will be seen. Have some one place a coin at this point and continue looking in this same direction; if the vessel is now filled with water to A D the coin will disappear from view at L. At the point N now seen upon the bottom, have another

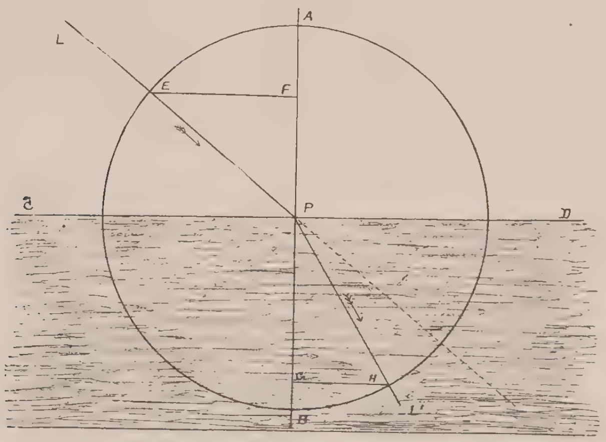

Figure 32.

Method of determination of index of refraction. Incident ray, L P; refracted ray, P L.

coin of different denomination placed so as to differentiate between the two. The coins are seen by the light they project to the eye. When the vessel was empty the light rays from M reached the eye at L along the straight line M A L, for they traversed only air between M and L; with water to the line A D and the eye at L, the coin at N is seen, showing that the rays from N reach the eye along the path N A L which is not straight. Were N A prolonged as a straight line it would reach the point F, which is nearer the perpendicular A E than L; rays following the path N A on emerging from water into air, a rare medium, are bent away from the perpendicular A E.

The deviation of light when refracted varies with the angle of incidence and the density of the refracting medium. The angle of refraction increases as the angle of incidence is increased and becomes smaller as the angle of incidence is reduced until at zero there is no

deviation, (see figure 29) the incident ray being perpendicular. Of two media the angles of incidence being the same, that having the greater density will have the greater angle of refraction as it offers a greater resistance to the passage of the light waves. (See Fig. 27.)

It has been found that the measure of the angles of incidence and refraction bear a certain ratio to each other for any two given media; it is called the *index of refraction.*

To find the index of refraction for any two media, the angles o incidence and refraction being known, draw a circle, figure 32, with the point of incidence P as its centre, C D is the surface separating the media; draw A B perpendicular to C D through P. The incident ray L cuts the circle at E and the refracted ray L′ at H, from E drop a perpendicular E F to the line A B and from H another perpendicular H G to A B. Suppose that the line E F is 6/10 the length of the radius E P, 6/10 is called the sine of the angle E P A, which is the angle of incidence. Suppose that H G is 4/10 the length of the radius H P, 4/10 is the sine of the angle of refraction H P B. The sines of the two angles are to each other as 6/10 : 4/10, or 6 : 4 which equals 1.5; if the media taken in this example were air and glass, the index of refraction given would be correct, the index of the refraction of glass compared with air, the optical unit is about 1.5

The index of refraction is the ratio of the sines of the angles of incidence and refraction, for a ray of light passing from one medium into another.

When we speak of the index of refraction of any medium it is usual to consider its refractive value compared to that of air.

The index of refraction for any two media indicates the relation that the velocity of light in one medium bears to its velocity in the other.

We know that the degree of refraction that a ray undergoes is dependent upon the angle of incidence; the incident ray being perpendicular, or *normal* to the surface. there is no refraction; as the angle of incidence increases, the angle of refraction increases rapidly until finally it forms 90 degrees with the perpendicular and such an angle of incidence is called the *critical angle;* if the angle of incidence be still further increased, the angle of refraction becomes greater than 90 degrees, and no light passes into the second medium, because on meeting the surface bounding the media it is refracted, or really reflected, back into the same medium; thus, whenever the incident ray from a dense into a rarer medium meets the surface bounding the media at an angle greater than the critical angle it is *totally reflected.*

Figure 33 represents a vessel filled with water to the line A B. A ray of light from D to C is normal to A B and is not refracted but passes to D′; the ray L meets A B at C forming the angle of incidence L C D and is refracted in the direction L′; another ray M forms the angle of incidence M C D and is refracted in the direction M′; the ray N forms the angle of incidence N C D and its angle of refraction is D′ C N′ which is 90 degrees, N′ being parallel to the surface A B, N C D is then the critical angle; the ray O forms the angle of incidence O C D which is greater than the critical angle and at C the ray O is bent in the direction O′, it is therefore not transmitted into the second medium but reflected. To simplify the tracing of the path of each ray in the figure (33) a different form of broken, dotted and unbroken line is used for each.

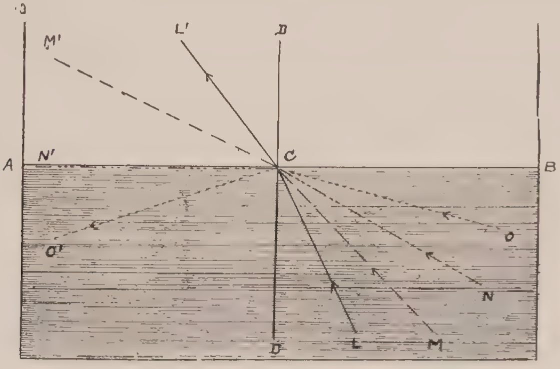

Figure 33.

Total reflection, Incident rays, D, L, M, N. O; refracted rays, L M′ N′; reflected ray O′; critical angle, N C D.

If a coin be placed in a glass filled with water and the glass held so that in looking upward at an angle upon the surface of the water, the coin will be seen mirrored upon the surface. This property of total reflection is the basis for the angles of the facets upon gems, by total reflection their brilliancy is obtained. The reason that we have daylight after sunset is due to total reflection of some of the light by the atmosphere.

CHAPTER II.

LENSES.

WE have proved (Figure 30) that when the surfaces of any transparent medium that receive and transmit light are not parallel to each other, that refraction occurs to the transmitted rays; that the degree of deviation is dependent upon the relative positions of the bounding surfaces (Figure 30), the angle of incidence (Figure 32), and the index of refraction (Figure 26). The medium best adapted to general use for purposes of optical refraction is *glass*, and in speaking of the refractive medium hereafter, glass will be meant unless otherwise indicated. The index of refraction of glass being known, to obtain a given degree of refraction, it is only necessary to determine the relative positions of the bounding surfaces.

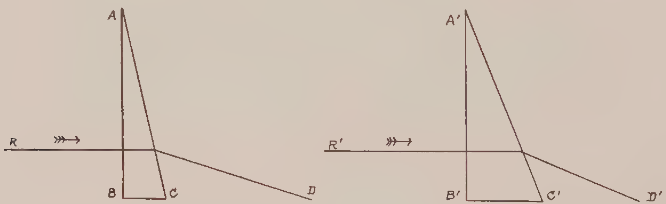

Figure 34.

Optical prisms; A, the apex; B C, the base; R, incident ray refracted to D. A′ B′ C′ possesses more refracting power than A B C.

Let figure 34 represent two refracting instruments, A B C and A′ B′ C′; the length of the sides A B and A′ B′ are the same, and A C and A′ C′ are also the same length. B C is shorter than B′ C′; therefore, the angle B A C is smaller than the angle B′ A′ C′. It has been demonstrated that of these two instruments A′ B′ C′ possesses the greater power of deviation of light, so that if the lines B C

and B′ C′ be prolonged as straight lines, the refracted ray R will meet A B at D and R′ will meet A′ B′ at D′; the distance C′ D′ will be less than the distance C D. Such a refracting instrument is called a *prism.*

An optical prism is a piece of glass, or other transparent material, whose two plane surfaces that receive and transmit light, form an angle with each other. The line where the surfaces meet is called the *apex* of the prism, the third surface of the prism is called its *base.* In figure 34 the apex of the prism A B C is at A, the base is B C.

A prism always refracts light toward its base.

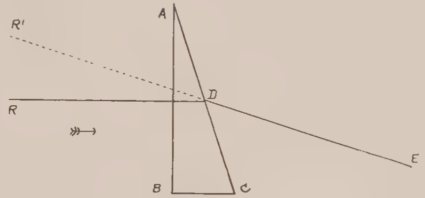

Figure 35.

Optical effects of a prism; R D, incident ray, D E refracted ray bent toward the base B C; R, actual position of object; R′, apparent position of object toward the apex when viewed from E through the prism.

The position of an object is apparently in the direction from which the rays of light from the object enter the eye. Figure 35 represents a prism A B C, the ray R is refracted at the point D toward the base and enters the eye placed at E as coming in the direction D E; if E D is extended back through the prism in a straight line, it will pass through the point R′ and to the eye the ray will appear as coming from R′, which will seem to be the location of the object situated at R

The optical effect of a prism is to refract light toward its base, but an object seen through a prism appears displaced toward its apex.

If two prisms of equal measurements be placed base to base, two rays incident upon identical points of each prism will meet after refraction at the same point upon a line that is an extension of their base line, if the incident rays are parallel to this line

Figure 36 will represent three forms of prism A B C, each placed base to base with a corresponding prism D B C. The rays R and S are parallel to the line B C and the incident points E and F are identical points upon the surfaces A B and D B. By identical points it is meant that one point is located upon one surface in a position corre-

sponding to the location of the other point upon the second surface. The ray R is refracted and if B C is extended as a straight line, R will meet B C at a point indicated as P; the ray S will also be refracted in a similar manner and its path intersects B C at P also.

As a circle may be regarded as a regular polygon, that is, a plane surface bounded by straight lines of equal length, and of infinite number; so a sphere may be regarded as a body bounded by an infinite number of equal plane surfaces.

If a section be cut from a sphere so that the surface made by the cut be a plane, we have a body bounded by one plane and one curved surface, every point upon the curved surface will be equally distant from the centre, (Figure 13), the curvature must therefore be the same in all meridians. If the spherical body be of glass, we have a refract-

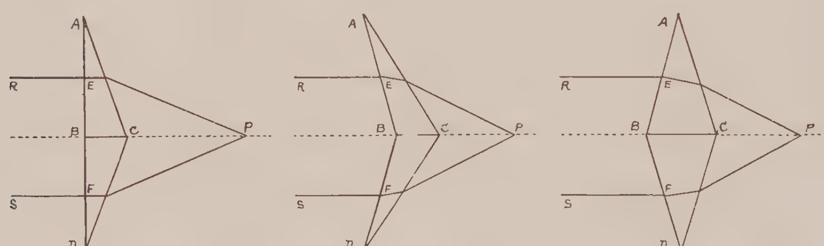

Figure 36.

Optical effects upon rays R and S parallel to base line B C of corresponding prisms bases together, rays incident upon identical points E and F.

ing medium whose power is alike in all meridians, as the relation of the two surfaces to each other is the same in all meridians.

The surface made by the cut may be concave or convex as well as a plane, the three conditions are shown in figure 37. Consider that the surface A C D is made up of an infinite number of small planes 1, 2, 3, 4, 5, 6, 7, etc.; the refractive condition created is that of two prisms of like measurements with their bases together. According to the law of refraction and the experiment illustrated by figure 36, rays incident upon the surface A B D meet at a point P upon a line passing through the points B C if the incident rays are parallel to this line; the point P, where the parallel rays meet after refraction by a curved surfaces is called the *principal focus*.

A transparent medium having one curved and one plane surface, or both surfaces curved, and having the power to bring rays of light to a focus is called a lens. A prism is not a lens, though it has been called such, it is incorrect.

The forms of lens shown in figure 37 are designated as *convex sphericals* as they are sections of a sphere; number I is a plano-convex, number II a concavo-convex, number III a double convex. The physical characteristics of all are the same, they are thick in the centre, thinner at the periphery (edge), and converge rays of light that they transmit. In every spherical lens there are two points, B and C figure 37, one upon each surface, so situated that a straight line may be drawn through these two points and the centre of curvature of the surfaces; a ray of light whose path follows this line suffers no refraction, this line is called the *principal axis* of the lens; the *principal focus* of a lens is a point situated upon this line and is where the rays that are parallel to the principal axis meet after refraction. At some point

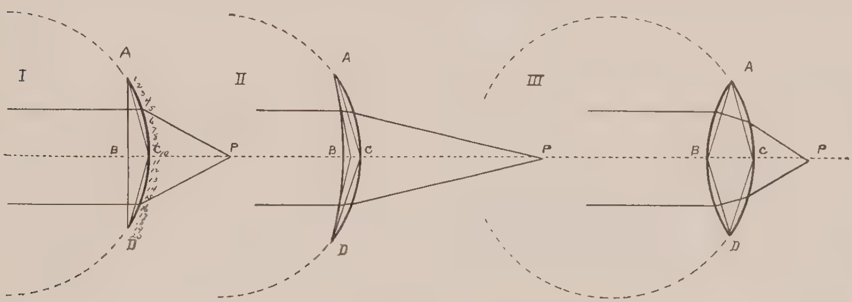

Figure 37.
Spherical lenses are sections of spherical bodies.

upon the principal axis is located a point called the *optical centre* of the lens, in number III, figure 37 it is located half way between the points B and C. The optical centre of a lens is the point through which rays of light pass without being refracted; this due to the fact that the small planes upon the surfaces of the lens pierced by such rays are parallel planes. Any ray passing through the optical centre of a lens except that traversing the principal axis, forms a *secondary axis* which is practically an unbroken line, the incident and emergent rays being parallel and but slightly displaced even in the higher power lenses. The *focal length* of a lens is the distance between the optical centre

and its principal focus; the greater the power the shorter will be the focal length.

Concisely described; an optical lens is an instrument made of a transparent medium that refracts light according to an established system, it is usually of glass, of a known index of refraction, with two surfaces of a certain ratio of curvature giving a definite focal power.

There are certain forms of glass used in spectacles and eyeglasses that are commonly called lenses but that are not correctly designated any more so than that a prism is a lens. If the surfaces of a piece of glass or other transparent medium be parallel as shown in figure 29, there is no refraction and we call such a *plano glass.* The surfaces

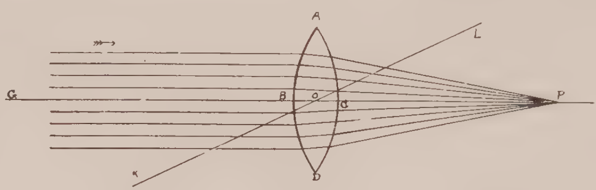

Figure 38.

Convex spherical lens. Principal axis, G P; optical centre O; principal focus P; secondary axis, K L.

may also be curved but so related that their effect is the same as if they were parallel planes and there is no refractive power, such should be called *curved plano glasses* and not lenses. The trade (optical) name for such is coquille and mi coquille glasses.

Figure 38 represents a double convex lens A B C D, the principal axis will be G P, the optical centre is located at O, the rays parallel to the principal axis are converged to the principal focus P. If light

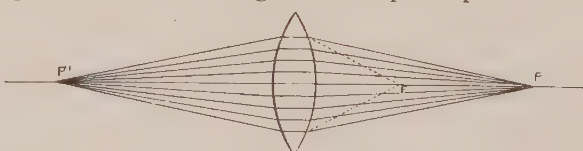

Figure 39.

Convex spherical lens. Principal focus, F; conjugate foci, P and P′.

be situated at the principal focus of a convex spherical lens, the rays will undergo refraction and emerge as parallel. If the light be placed between the principal focus and the lens the rays will emerge divergent, but not so divergent as they enter; if the light be beyond the

principal focus the rays will emerge convergent. The straight line K L represents a secondary axis, as it passes through the optical centre O.

Figure 39 shows a convex lens whose principal focus is at F, light from the point P beyond the principal focus is converged and focused at P′; these two points, P and P′, bear a certain defined relation to each other and are called *conjugate foci;* either may be taken as the location of the luminous point, at the other the rays will be focused and form a *real image* of the luminous point.

To show the formation of an image of the object by a convex spherical lens, let A, figure 40, represent the lens, its optical centre at O, its principal focus at F; L and M indicate two points upon the object situated a greater distance from the lens than its focal length. The path of a ray from the point L parallel to the principal axis will

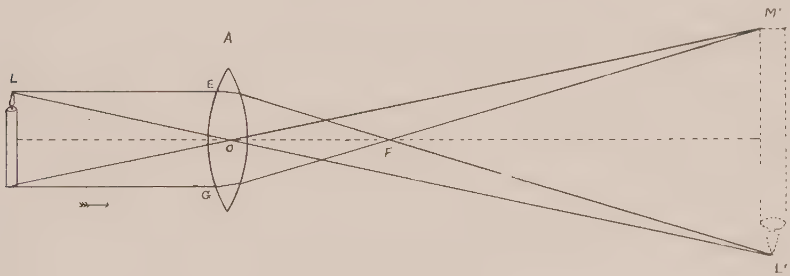

Figure 40.

Formation of image by convex spherical lens. F, the focus; L M, the object situated a greater distance from the lens than its focall ength; L′ M′, the image, real, inverted and magnified.

be incident at E and will be refracted through the principal focus F, the path of another ray from L through the optical centre O will meet E F at L′ which will locate the image of the point L; in the same way locate the image of the point M at M′. It can thus be shown that light from every point upon the object is directed to its corresponding position in the image.

A convex spherical lens creates a real inverted image of an object by focusing upon a screen the divergent rays from every point upon the object, the collection of foci creating the image.

Take a convex lens L, figure 41, of say ten inches focal length and place a lighted candle at its principal focus A, the light will be refracted as parallel rays on emerging from the lens and the image of

the candle will be at infinity (practically no image is formed), if the candle be placed at the point C twenty inches from the lens, just double its focal length, a sharp image of the flame will be projected upon a screen held at C′ twenty inches from the lens and this image

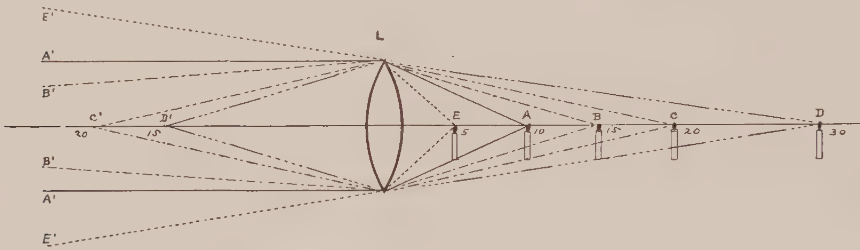

Figure 41.

Position and size of image formed by a convex spherical lens, the object in various positions with regard to the focus of the lens. A different character of line joins each object and its image.

will be the exact size of the flame. If the candle be removed further from the lens than twice the focal length say to D thirty inches away, the image may be received upon a screen at D′ fifteen inches from the lens and the image will be smaller than the flame, in fact just half the size. If the candle be placed between the positions A and C at B, that is, between the focus and twice the focal length, the image will be larger than the flame, and more than twice the focal length removed from the lens If the candle be placed at E, nearer to the lens

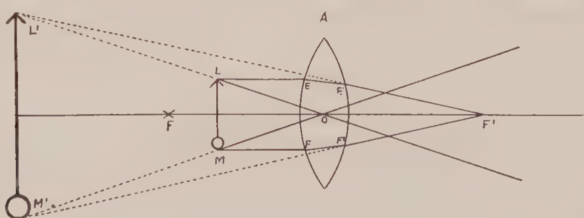

Figure 42.

Showing that the image L′ M′ of the object L M situated nearer the lens than the focal point F is virtual, erect and magnified.

than its focus the rays will emerge divergent as shown by E′ E′ and no real image will be formed. To facilitate locating the paths of rays from the various positions shown, each is indicated in the figure by a line of different character.

The size of the image created by a convex lens, is to the size of the object, as their distances from the optical centre of the lens are to each other.

A comparison of the phenomena illustrated by figures 41 and 22 will be interesting and instructive, the student should not fail to make the experiments illustrated by figures 41 and 43.

As shown by figure 41, rays from an object situated nearer to the lens than its focal length are divergent after refraction, the image thus created is *virtual* only. Let figure 42 represent a convex lens A whose focus is at F, the object being placed at L M which is nearer to the lens than its focal length. Let a ray from L parallel to the principal axis meet the lens at E and it is refracted through F′, another ray from L through the optical centre forms a secondary axis L O; by extending O L and F′ E′ upon the same side of the lens as the object we find their virtual focus and thus locate the virtual image of L at L′. In the same way locate the virtual image of the point M at M′; it is found that *the image is erect, virtual and magnified.* This property of a convex lens is made use of to construct an instrument called a microscope; the action of a simple microscope can be nicely demonstrated by the following experiment.

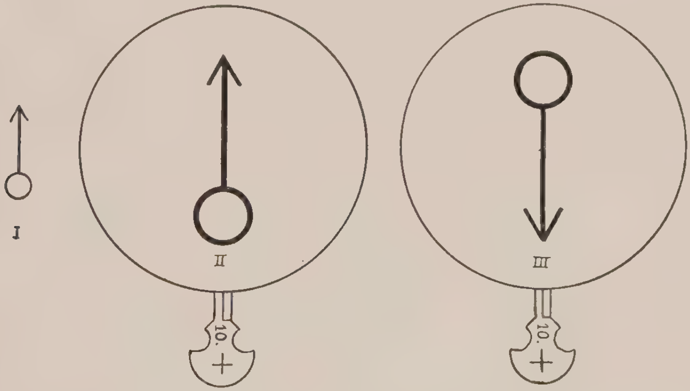

Figure 43.
Object I. viewed through a convex lens; II. the lens held nearer the object than its foca length; III. the lens held beyond its focal length.

Draw a figure similar to I, figure 43 upon a sheet of paper, before it hold a strong convex lens quite close to the paper, the effect shown by II will be created, the figure will appear erect and magnified; if

the lens be withdrawn gradually from the figure it increases in size rapidly, remaining erect and finally disappears, which indicates the focus has been reached. Removing the lens still further the figure reappears as shown by III, it is inverted and magnified and as the lens is still further withdrawn its size is diminished.

All the rays from any point of an object do not meet after refraction by a spherical lens at exactly the same point and this creates what is known as *spherical aberration*. The result of spherical aberration is to give a blurred image and create distortion.

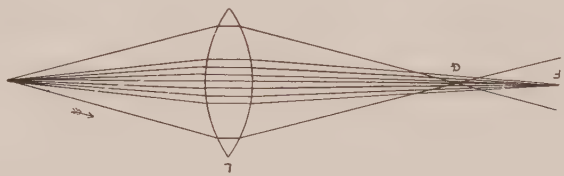

Figure 44.

Spherical aberration; F, approximate focus of central rays; G that of the marginal rays.

Figure 44 illustrates the principles of aberration of a spherical lens L; the rays incident upon the lens form varying angles with the small planes of the surface, the ray whose path follows the principal axis is normal to the plane at the point of incidence while the path of a ray that is incident upon a plane at the periphery forms the greatest angle of incidence. The rays that are refracted by the central portion of the lens have their focus approximately at F while those that are refracted by the edge of the lens have a focus approximately at G, a point nearer to the lens. This would prove that the edges of a spherical lens possess greater power of refraction than the centre, and this is true, the effects created are not so noticeable in the weaker power lenses as in the stronger ones, a lens of two inches so called focus has a focal power at the periphery of about 1.6 inches, which gives a quite blurred image. The degree of aberration increases with the size (aperture) of the lens and the power, also the form of the lens and the distance of the object A double convex lens has the greatest aberration, and gives the most distortion, a plano convex less, and a periscopic the least.

Persons who have worn glasses for years of a certain form find it difficult in some instances to use the same power lens but in another form; it will be well to remember this fact as it may explain what may otherwise seem to be an imaginary grievance of some glass wearer. In cameras and some other optical instruments, the aberra-

tion is corrected by the use of a diaphragm that cuts out the peripheral rays and sharpens the image. In the eye this diaphragm effect is supplied by the iris.

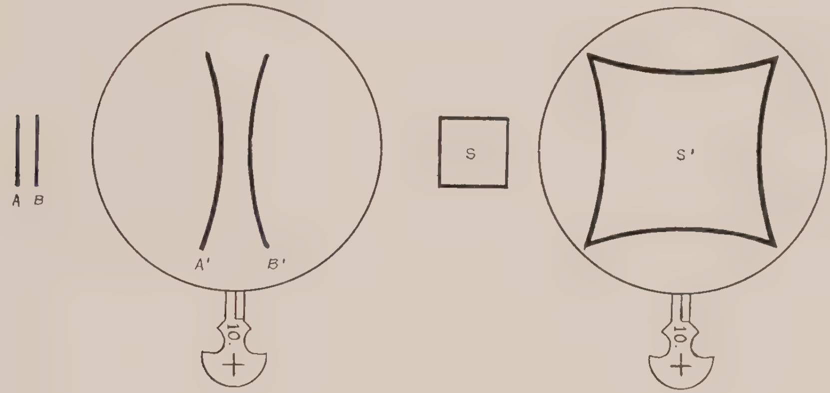

Figure 45.

Distortion of objects created by looking through strong convex lenses, the square S is distorted into the curved sided figure S'; etc.

Figure 45 shows how objects appear distorted when viewed through a strong convex spherical lens, the two vertical parallel lines A and B are greatly magnified when seen through the lens, they are

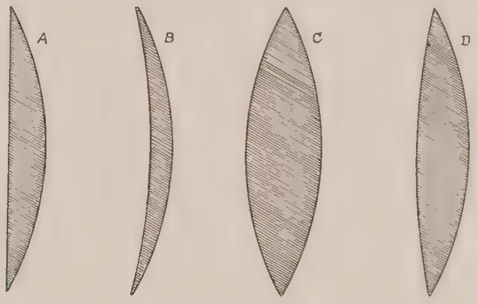

Figure 46.

Types of convex spherical lens. A, plano-convex; B, concavo-convex, meniscus, or periscopic; C and D, bi-convex or double convex.

no longer straight but appear as two curved lines A' B' with their convex sides toward each other. The square figure S becomes a figure

S′ bounded by four curved sides, their convexity toward the centre. A familiar evidence of spherical aberration is seen in photographs of street scenes in which the buildings have the appearance of being about to topple into the centre of the street, the effect is created by the spherical aberration of the lens of the camera.

The sections cut from the transparent spherical body illustrated by figure 37, to which has been given the name of convex spherical lenses, types of which are shown in figure 46; A being a plano convex, B a concavo convex or meniscus (also called a periscopic), C and D double or bi-convex. These lenses all have certain optical properties that are alike. If we place them upon a sheet of paper and with a pencil outline the edge, the figure drawn will be a circle, see I, figure 47; draw two lines at right angles to each other that will be diameters of the circle and they will intersect at the centre, place the lens upon this figure so that its edge corresponds to the circumference

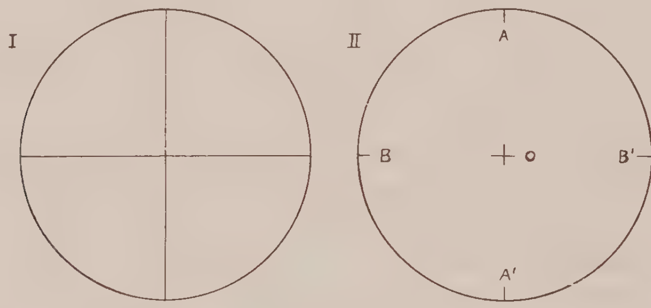

Figure 47.
Marking the geometric and optical centres of a lens.

of the circle and with india ink and a fine hard wood point (a piece of "jewelers peg wood" makes the best point for this purpose) mark carefully at the periphery of the lens the four points A A′ B B′, indicating where the diameters meet the circumference; also mark a cross at O to indicate the centre, the lens will thus appear as shown by II, figure 47. The cross will thus mark the *geometrical centre* of the lens and also its *optical centre*, being the point upon its surface in the principal axis.

By figure 37 it is demonstrated that the ray traversing the principal axis and therefore passing through the optical centre is not refracted. If we draw a vertical straight line, I, figure 48, upon a piece

of paper and hold the lens so that in looking at the line S L through it our line of vision follows the principal axis, the line will appear unbroken and passing through the points A and A′ as shown by II, figure 48. Move the lens to the *right* in the same plane, and the

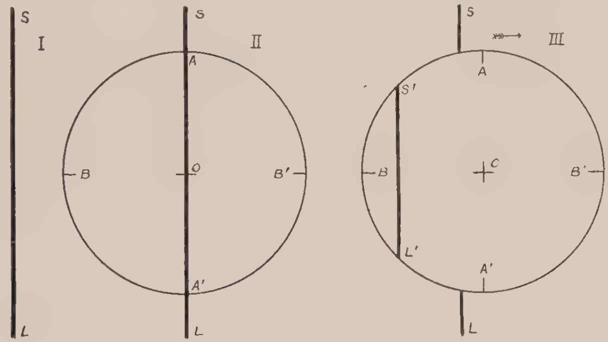

Figure 48.

The appearance of a vertical straight line through a convex spherical lens; II, the line of vision passing through the optical centre; III. lens moved to the right, line S′ L′ displaced to the left.

appearance created will be illustrated by III, figure 48, the points A and A′ will appear to the *right* of the line S L while the portion of the line, S′ L′, seen through the lens will appear displaced to the *left*.

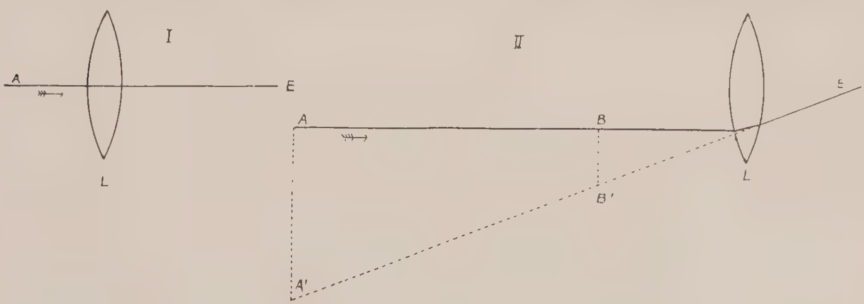

Figure 49.

Cause of apparent displacment of object by convex spherical lens; also comparison of degree of displacement if object were at A or B.

This phenomena will be explained by reference to figure 49, I represents the first position of the lens, the visual line from the eye at

E to the object A corresponding to the principal axis; II represents the second position of the lens, the visual line now passed through a prism and the object while actually occupying the same position as before at A appears displaced to A′ toward the apex of the prism, (figure 35) this gives foundation for the following law.

When an object is viewed through a convex spherical lens and the lens is moved laterally, the object appears to move in the opposite direction.

The amount of displacement that the object appears to undergo, depends upon the power of the prism (strength of the lens) and the distance from the lens of the object viewed. If the object were situated at A, shown by II, figure 49, it would appear as displaced to A′ while if at B, a position nearer the lens, it would seem to be located at

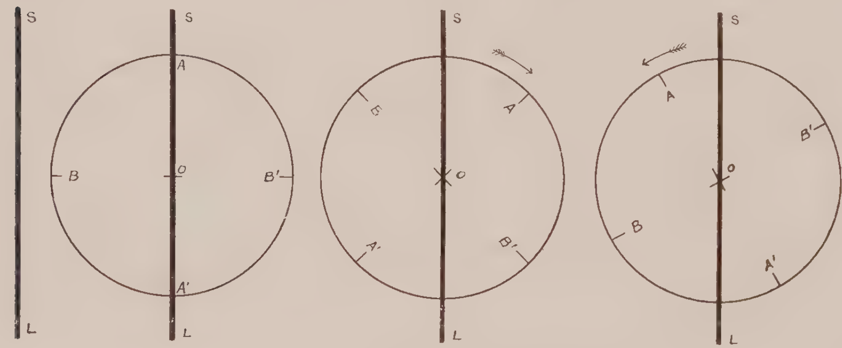

Figure 50.

Appearance of vertical line seen through convex spherical lens rotated about its centre but not displaced, no displacement of the line S L.

B′; the distance from A to A′ is greater than that from B to B′, though each is created by the same movement of the lens L.

The stronger the lens and the greater the distance of the object from it, the more rapid will be the movement of the object.

If an object be viewed through a spherical lens, the lens may be rotated upon its principal axis and the object will not be distorted by the act of rotation.

Figure 50 will illustrate the straight line S L seen through the lens in various positions rotated about its centre, so long as the lens is not displaced but merely rotated, no change in the appearance of the

object is created, for the spherical lens possesses like power in every meridian.

A convex spherical lens will be recognized; first, by the fact that upon rotating it no distortion occurs of an object viewed through it; second, look through it at some object at as great a distance as possible, preferably a vertical straight line, and move the lens back and forth with a pendulum like motion, if convex the object will move opposite to the movement of the lens.

"Uncut lenses" are sold by the makers, having a given focus but not edged, the blanks average about 45 millimeters square; from these, lenses of various forms may be cut. In order to find the optical centre of these irregular shape lenses, draw upon a paper two straight lines in the form of a cross, the lines must be at right angles to each

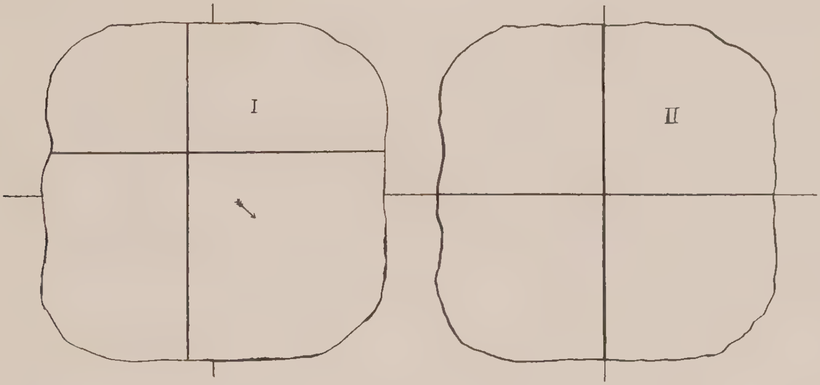

Figure 51.
Marking the optical centre of an irregular shape spherical lens; II. the straight lines at right angles to each other are unbroken, indicating centre where they intersect; I appearance in another position.

other, hold the lens in such a position before the crossed lines that they appear unbroken through the lens as shown by II, figure 51, any deviation from this position will create an effect similar to that illusstrated by I, figure 51. Having located the centre, mark the irregular lens the same as was done in figure 47, and the form for the desired size and shape lens can now be imposed with its geometric centre upon the optical centre of the lens and this form outlined upon the blank, this will give a properly *centred* lens. To ascertain if any lens

is properly centred, proceed as above and see if the optical and geometrical centres correspond. Sometimes it is desired to *decentre* a lens, or to have the optical centre located in a certain position with

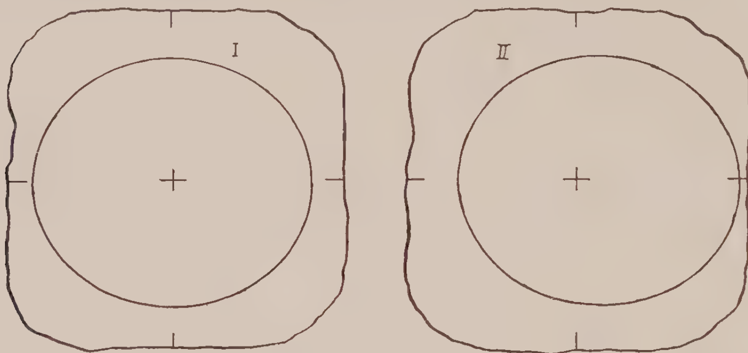

Figure 52.

I. Geometric and optical centres of lens identical; II. geometric centre purposely displaced from optical centre, giving a "decentered" lens.

regard to the geometric centre. I, figure 52, shows a centred lens, II, figure 52, a decentered one marked out upon the blank.

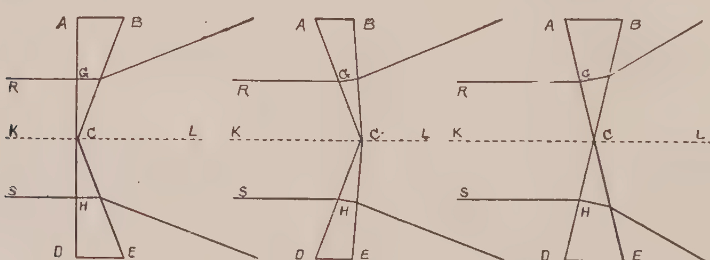

Figure 53.

Optical effects of corresponding prisms apices together upon parallel rays of light.

In figure 36, pairs of similar prisms base to base are shown, figure 53 shows the optical effect of pairs of similar prisms with their apices together. C is the apex of the prisms A C B and D C E, the

ray K L is not refracted, but the rays R and S incident upon the identical points G and H are refracted alike, and from being parallel are rendered divergent. Figure 37 illustrates a form of optical instrument having surfaces that are sections of a sphere so related

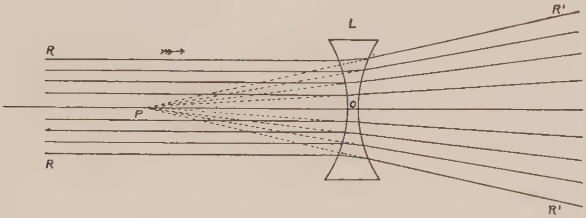

Figure 54.

Concave spherical lens; R, incident rays; R′, refracted rays; P. virtual focus; P. O, principal axis.

that they have certain optical properties. Figure 54 represents another form of lens having two spherical surfaces so related that they create optical effects that are exactly the opposite of convex

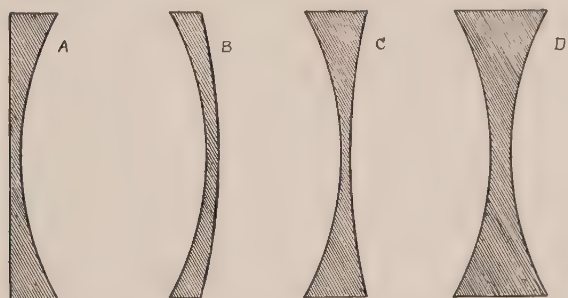

Figure 55.

Types of concave spherical lens; A, plano concave; B, convexo-concave, meniscus or periscopic; C and D, bi-concave or double concave.

spherical lenses, they are termed *concave spherical lenses.* It will be seen that the parallel rays R in passing through the concave lens L are refracted as divergent rays R′ and therefore can never meet, so that they are not brought to a focus. A concave lens therefore has no real focus but only a *virtual focus* which is located by ex-

tending the divergent rays back to a point where they would meet, as P figure 54. Various types of concave spherical lenses are illustrated by figure 55; A is a plano-concave, B a convexo-concave, or periscopic, C and D double or bi-concave. It will not be necessary to go all over the characteristics of the concave lens as they are similar to those of the convex, but of the opposite effect. A few words however will not be amiss. They are thin in the centre, thicker at the periphery, possess the same faults of aberration and distortion, if they are rotated upon their centre they do not distort the object viewed

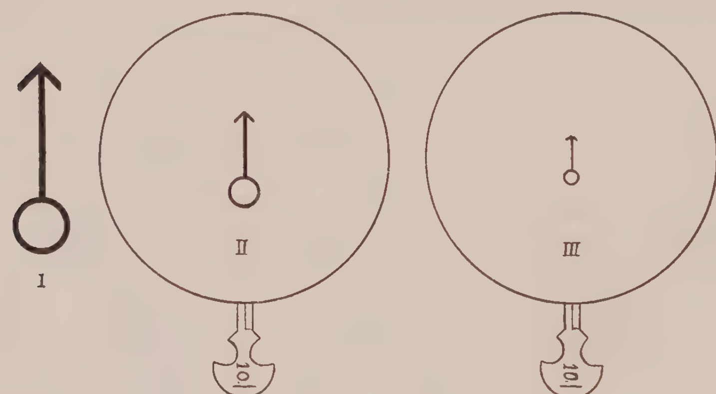

Figure 56.

Appearance of an object through a concave spherical lens.

through them. They are centred or decentred in the same way. The effect created by looking through such lenses is to make the object appear smaller; figure 56 shows a figure I of a certain size and form, II shows this same figure seen through a concave lens at a given distance, III the same figure with the lens further removed, showing that the greater the distance of the object from the lens the smaller it will appear to be.

Repeat experiment illustrated by figure 50, using a concave lens and no difference will be detected between the convex and concave; however, if experiment illustrated by figure 48 be made with a concave lens the results will be shown by figure 57. The lens being moved to the right, the portion of the line S′ L′ seen through the lens

also appears to the right of the line S L or with the movement of the lens.

A convex lens can be distinguished from a concave, by the fact that an object moves against the lens movement of a convex, and with the lens if it be concave.

In the chapter on light it was explained that light was composed of rays of various wave length that gave the effect of color, a prism possesses the power of separating white light into its component parts. If a band of light be admitted through a slit A figure 58, and transmitted by a prism P upon a screen S, it will be separated into a luminous band showing the colors of the spectrum, this is termed the

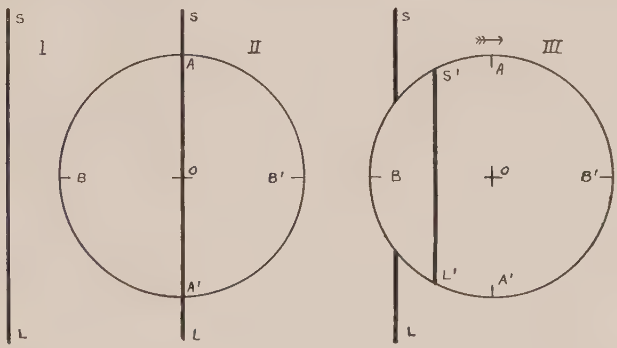

Figure 57.

The appearance of a vertical straight line through a concave spherical lens; II, the line of vision passing through the optical centre; III. lens moved to the right, line S′ L′ displaced to the right.

dispersion of light and is due to the difference of the degree of deviation of the various rays by refraction Red is deviated the least and is said to be the least *refrangible* color, and in the order of refrangibility come, orange, yellow, green, blue and violet, the violet being the most refrangible color. This creates in lenses what is termed *chromatic aberration*, the images formed by strong spherical lenses are tinged with these colors.

In figure 58 the spectrum color band is shown as having seven colors, but it is merely a sub-division of the blue into two shades, cyan-blue and ultramarine blue, according to a later idea of the spectrum.

Having found that various powers may be obtained in lenses, some method of numbering or indicating their power must necessarily be devised. Almost all knowledge is obtained by comparisons with something that we can easily comprehend, thus we form our estimates of height, distance, value, etc. by adopting some definite *unit* with which to calculate multiples or sub divisions. As the most convenient property of a lens upon which to base a system of numbering is to measure its length of focus it was natural to note this in inches, the inch being the linear unit. *A lens having a focal length of one inch was therefore adopted as the unit*, this really established a uniform

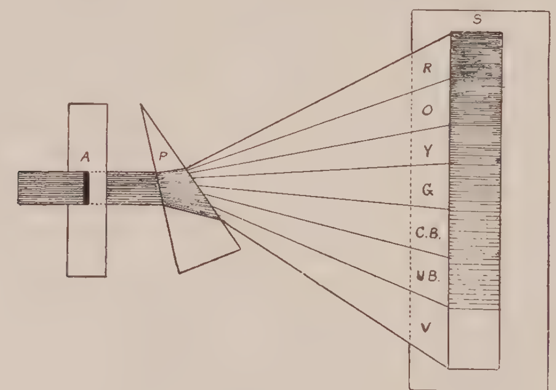

Figure 58.

Dispersion of light by a prism. Band of light passing through slit A, transmitted by prism P, forming spectrum band S.

system of numbering which was a great improvement over older methods, by which each lens grinder distinguished certain lenses by a name, or a number that represented a totally different value from that of another maker. While an improvement, the "*inch system*" left much to be desired. Of a one inch lens it may safely be said, it is never used in the correction of an error of refraction, those that are used being weaker, it is necessary to indicate their value in fractions. A lens having a length of focus of four inches would be of but one-fourth the power of the unit, one of thirty-six inches focus should be termed a one-thirty-sixth. From this method it has become customary to speak of a number ten lens, meaning really a one-tenth focal power; a number twenty-four is a one twenty-fourth; the larger number thus indicated the weaker power.

So long as the use of glasses was confined to aiding elderly people to read and work at close point with more comfort, and now and then helping a near sighted person to enjoy better vision, the glasses being merely convex or concave sphericals, and the calculations being of the simplest kind compared to those of to-day, this system answered fairly well. With the increase of the knowledge of optics and the consequent widening of the optical field, due to a growing demand for glasses, it having been discovered that they could bring relief to young and old alike, the inch system proved too awkward to handle. The greatest objection is the fact that in combining lenses of different character and focus the calculations had to be made in fractions. Suppose that it is desired to combine a one-fifth and a one twenty-sixth lens, it is necessary to resort to pencil and paper with this result:—

$$\frac{1}{5} + \frac{1}{26} = \frac{26}{130} + \frac{5}{130} = \frac{31}{130} = \frac{1}{4\ 6/31}$$

This is an every day experience and with a busy operator would have

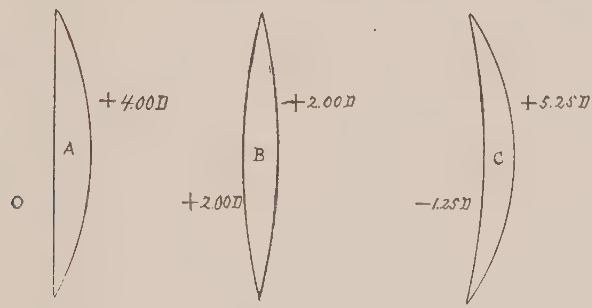

Figure 59.

Equal convex spherical value obtained by unequal curvatures, the power of the lens being that of the two surfaces combined.

to be done many times a day; the liability to error, and its inaccuracy is plainly seen; leaving out entirely any consideration of the time required for such calculations.

The decimal system was advocated and the logical result was a resort to the "metric system." Profiting by the experience with the inch system, a weaker power was selected, and a lens having a focal length of one meter was adopted as the unit. To this system was

given the name "*Dioptric*;" the standard lens was said to be *a one dioptry lens* and had a focus of one meter; a four dioptry lens has four times the power of the unit and therefore focuses at one fourth of a meter. By comparison, the meter is found to be 39.5 inches in length, but for convenience of transposing inches into dioptries, or dioptries into inches, it is considered to be 40 inches. A simple rule for the transposition of a lens from the numbering of one system into that of the other is as follows:

Divide 40 by the number of the lens expressed in inches, the result will be its value in dioptries. Divide 40 by the number expressed in dioptries, the result will be its focus in inches.

Examples:—	40 ÷ 10 inches	= 4.00 dioptries.
	40 ÷ 13 "	= 3.00 "
	40 ÷ 16 "	= 2.50 "
	40 ÷ 26 "	= 1.50 "
	40 ÷ 5.00 dioptries	= 8 inches
	40 ÷ 0.50 "	= 80 "
	40 ÷ 1.25 "	= 32 "
	40 ÷ 8.00 "	= 5 "

For comparison, suppose we take the same example we had in inches to combine; a one fifth lens is eight dioptries, a one-twenty-sixth is one and a half dioptries.

8.00 dioptries + 1 50 dioptries = 9.50 dioptries.

This calculation can easily be made without the aid of paper and pencil and in a moment, its advantages over the other system are obvious.

Another defect in the inch system that does not obtain in the dioptric system, is the lack of uniform differences between the lenses, thus:—the difference between a 1/7 and a 1/8 inch lens is 1/56, while the difference between the next successive numbers a 1/8 and a 1/9 inch lens is 1/72. This difference between successively numbered lenses is greater as they increase in power; the interval between any two successive lenses is never the same as that between any other two successive lenses numbered by the inch system. In the dioptric system of numbering the differences are regular. The dioptry is readily sub divided to indicate the power of lenses weaker than the unit, one-half, one fourth and one-eighth are indicated respectively as 0.50, 0.25 and 0.12. This may seem to be carrying the system to extremes, but such power lenses are used daily in the correction of the errors of refraction with decidedly beneficial results so that they occupy an important place in the field of optics and are constantly involved in necessary calculations

A comparative table of the dioptric and inch systems, showing the approximate value in inches is here given.

Dioptric System.	Inch System.
0.12	320
0.25	160
0.37	108
0.50	80
0.62	60
0.75	52
0.87	44
1.00	40
1.12	36
1.25	32
1.50	26
1.75	22
2.00	20
2.25	18
2.50	16
2.75	14
3.00	13
3.25	12
3.50	11
3.75	10 1-2
4.00	10
4.50	9
5.00	8
5.50	7
6.00	6 1-2
6.50	6
7.00	5 1-2
8.00	5
9.00	4 1-2
10.00	4
11.00	3 1-2
12.00	3 1-4
13.00	3
14.00	2 3-4
16.00	2 1-2
18.00	2 1-4
20.00	2
40.00	1

The adoption of the dioptric system is one of the signs of progress of optics from a commercial to a professional basis, and its advance to a science.

To make the system complete and more convenient for the purpose of calculations and record, certain arbitrary signs and abbreviations are adopted. Spherical is written Sph. or S; dioptry is abbreviated to D.; dioptric-spherical is shortened to D. S. or D. Sph. The sign + (plus) is the conventional mark used to indicate convex curvature of a lens surface while the sign for concave curvature is — (minus). These same signs are also used to indicate the character of a lens; thus, the sign + means a convex lens, the sign — signifies a concave lens. A lens may have a — (concave) curvature upon one surface and a + (convex) curvature upon the other; its + (convex) or — (concave) refractive value will depend upon which is the greater. In figure 59, C represents a lens having a — 1.25 D. curvature upon one surface, a + 5.25 D upon the other, the value of the lens is a + 4.00 D. These

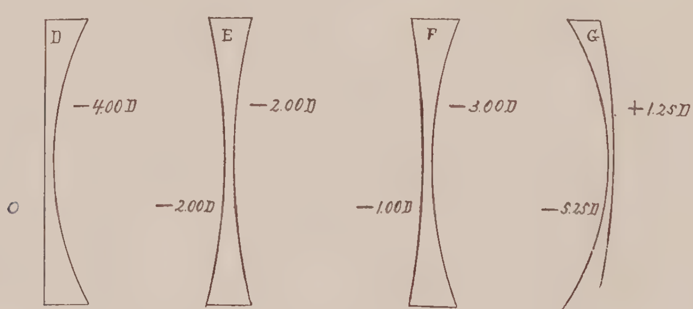

Figure 60.
Equal concave spherical value with unequal curvatures.

are the usual curvatures for "Periscopic" lenses of convex value, a — 1.25 D. being used for the posterior (inner) surface and the required convex being given the anterior (outer) surface. The concave curvature is placed next to the eye. A, figure 59, shows a plane surface ocmbined with a + 4.00 D. curvature; B, figure 59, illustrates a + 2.00 D. curvature on each surface of the lens; the refractive values of A, B and C, figure 59 are all alike. Figure 60 represents lenses having a concave value, D has a plane surface combined with a — 4.00 D.

curvature, E a — 2.00 D. upon each surface, F a — 1.00 D. upon one surface, with a — 3.00 D. on the other, G the usual form of periscopic concave lens, + 1.25 D. upon the anterior surface, — 5.25 D. on the posterior, the concave surface is placed toward the eye. All the forms represented by figure 60 are of the same power.

The following shows various forms of correctly written lens values in the dioptric system, those in the first column are to be preferred as admitting of less error, beside being simple and to the point.

+ 1.00 D. S.	+ 1.00 D. Sph.	+ 1. Sph.	+ 1. D.
+ 0.75 D. S.	+ .75 S.	+ .75 D.	+ .75 Sph.
+ 2.50 D. S.	+ 2.5 Sph.	+ 2 1/2 S.	+ 2.50 Sph.
— 1.50 D. S.	— 1.50 D.	— 1.5 Sph.	— 1.5 S.
— 0.50 D. S.	— 0.50 S.	— .5 D.	— .50 Sph.

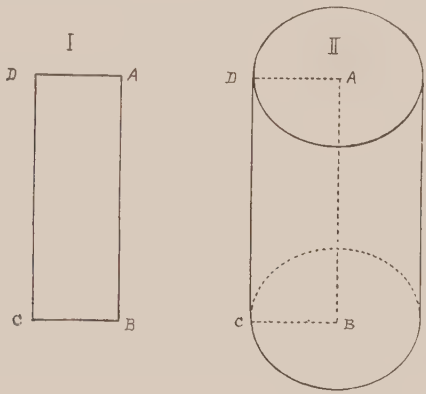

Figure 61.
Formation of a geometric cylinder.

Having become familiar with the optical properties of sections cut from a transparent sphere, to which has been given the name of spherical lenses, we will now consider another form of lenses that are sections of a different form of solid body having a curved surface, that is, a *cylinder*. Everyone knows in a general way what the form of a cylinder is, it might readily be said that a section of a piece of pipe or tubing is a cylinder, that a round lead pencil is a cylinder; but it will be just as well to give a little more definite description, and to that end we will consider its important characteristics.

Let I, figure 61, represent a rectangle A B C D, its opposite sides are equal in length and its angles are all right angles. Suppose the side A B to be fixed and the rectangle to revolve about it as an axis. The body illustrated by II, figure 61, would be created. The bases would be circles, A being the centre of one, B the centre of the other and the axis A B will be perpendicular to the plane of both bases. If

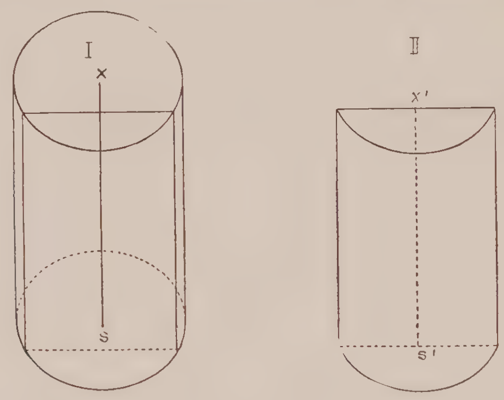

Figure 62.

Formation of a cylindrical lens, showing that it is a section of a cylinder. X S, axis of the cylinder; X′ S′, axis of the cylindrical lens.

such a cylinder were made of glass I, figure 62, and a section were cut from it, the line of the cut being parallel to the axis and the surface made by the cut being a plane, an optical instrument called a *plane cylinder* II, figure 62 would be created. X S indicates the *axis of the cylindrical body* and X′ S′ indicates the *axis of the cylinder lens.*

If the cylindrical body I, figure 62 were to be cut straight through along its axis, the appearance of its cross section would be as illustrated by I, figure 63, that is, a rectangle; if however the cut were to be made at *right angles to the axis*, a very different figure would illustrate its cross section, II, figure 63 being a circle. If the cylinder lens II, figure 62 were cut through its axis, its cross section would be illustrated by III, figure 63, while if the cut were made at right angles to its axis, its cross section would present the appearance of IV, figure 63. It is known that if a plano convex spherical lens be cut through its optical centre along any meridian the cross section would have exactly the same appearance as shown by IV, figure 63. By the

appearance of III, figure 63 it is seen that the cylinder possesses no refractive power in this meridian, the surfaces being parallel along these lines, the optical effect of the cylinder in this meridian is therefore that of plano-glass; in the meridian at right angles to this, by reference to IV, figure 63, it will be seen that the refractive power is that of a spherical lens

In a spherical lens the power is the same in all meridians, there is no need therefore to designate any special ones, in fact it would be impossible for the reason that they are all alike. In the cylindrical lens they are not similar, the power of the lens varies in each meridian. For purposes which will be seen later on, it is found necessary to designate the meridians in which the greatest and least power (or rather no power) obtains, as the *two principal meridians, and they are always at right angles to each other.*

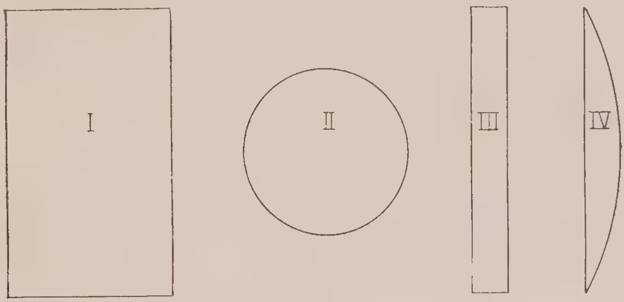

Figure 63.

Cross sections of geometric cylinder and cylindrical lens. I, through axis of the geometric cylinder; II, at right angles to this axis; III, through axis of cylindrical lens; IV, at right angles to its axis

Cylindrical lenses are convex or concave, their differences being similar to the difference between convex and concave sphericals. Let figure 64 represent a convex cylinder, it will be seen that one of the principal meridians must correspond to the axis X S and the other will be indicated by P M at right angles to it. It has become customary to say that a cylindrical lens has two axes, a major and a minor axis. This is correct, but the writer frequently finds that these terms are confusing to the student and he prefers to consider that the cylinder possesses but one axis, viz:—that meridian in which no refraction occurs, indicated in figure 64 by X S; at right angles to the

axis, in the meridian where the greatest refractive power of the cylinder exists, indicated in figure 64 by P M, he prefers to designate it as the *principal meridian* of the cylinder; a definition of a cylindrical lens according to this designation is as follows:

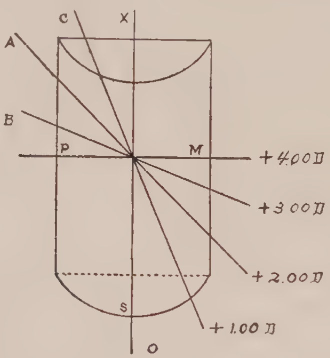

Figure 64.

Convex cylinder lens showing varying power in different meridians. X S, the axis; P M the principal meridian.

A cylinder lens possesses unequal power of refraction in various meridians; in the plane of the axis no refraction occurs, while at right

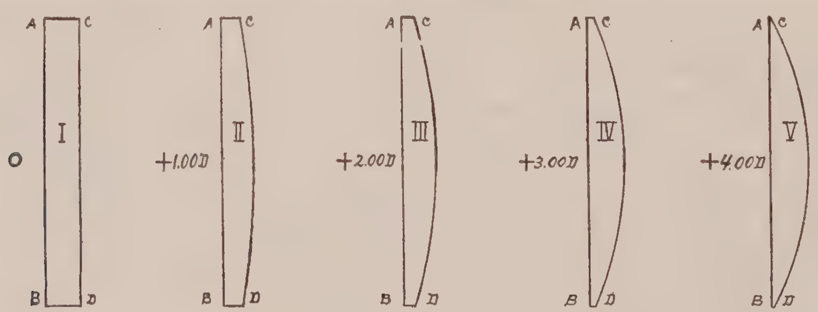

Figure 65.

Cross sections of a convex cylinder through different meridians. I, through the axis; V, through the principal meridian; II, III and IV, through intermediate meridians.

angles to the axis, in the plane of the principal meridian, the greatest refraction occurs.

Cylindrical lenses are numbered in both the inch and dioptric systems the same as spherical lenses, their power so indicated refers to the refractive value of the cylinder in its principal meridian. Let figure 64 represent a convex cylindrical of + 4.00 D., in the plane of the axis its power is O, while in the plane of the principal meridian the power is + 4 00 D. In the plane of a meridian A, situated equally distant frcm the axis and the principal meridian, the power is one half, or + 2.00 D.; in the meridian B, half way between A and the principal meridian the power is + 3.00 D.; in the meridian C, half way between A and the axis, the power is + 1.00 D.

The power of a cylinder iucreases as the principal meridian is approached and decreases toward the axis.

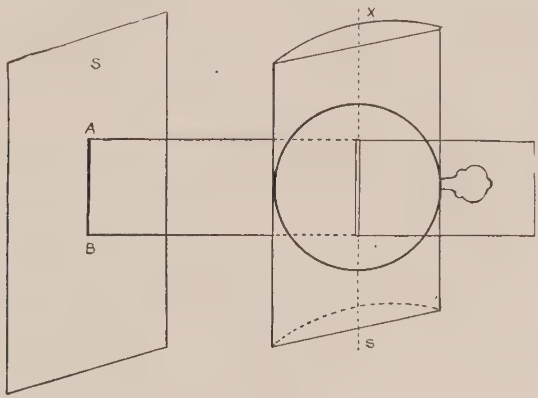

Figure 66.

Parallel rays of light transmitted by a convex cylinder, a stenopaic slit imposed paralle to the axis.

This will be explained by reference to figure 65. I, represents a cross section of the cylinder, figure 64, cut through its axis, A B and C D are parallel straight lines; II, figure 65, represents the cross section of the cylinder through the-meridian C, figure 64, where the power is + 1.00 D. the line A B is straight while C D is slightly curved; III, figure 65 is a cross section of the cylinder through the meridian A, the power being + 2.00 D. and C D assumes a greater curvature; IV, figure 65 shows a cross section of the cylinder through the meridian B, figure 64, the power being + 3.00 D. the curvature of C D is still

greater; V, figure 65 represents the cross section of the cylinder though the principal meridian with the power + 4.00 D. and the greatest curvature to C D. The curvature of II, III and IV is *parabolic*. The principal meridian alone possessing spnerical curvature it is therefore the only one having a focus.

The focus of a spherical lens is a point; the focus of a cylindrical lens, if we can so term it, is a line. Take a high power convex cylinder and focus the light upon a screen in a similar manner to the procedure with a spherical lens, and there will appear simply a bright line, *a cylinder lens therefore does not create an image*, in proof of this

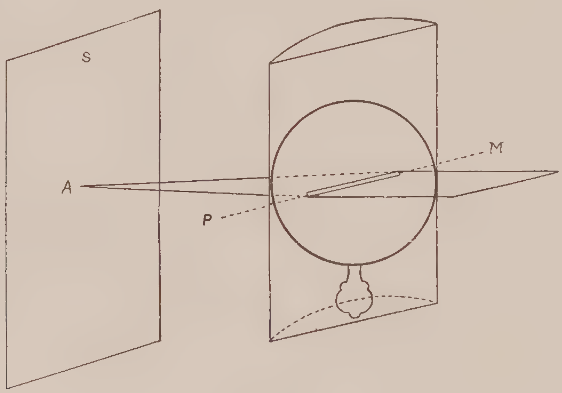

Figure 67.

Parallel rays refracted by a convex cylinder, a stenopaic slit imposed parallel to the principal meridian (at right angles to the axis).

look at a round spot of light through a strong convex cylinder and it will appear as a strip of light, being distorted from its real form. This is the principle upon which the "Maddox Rod" is constructed; it will be described later on.

Let figure 66 represent a convex cylinder, before it is placed an opaque disk having a straight slit in it, the slit is parallel to the axis X S with the result that the light passing through the slit reaches the screen S as a strip A B, showing that in this meridian no refraction takes place, the parallel rays emerge from the lens parallel and so reach the screen. Such an opaque disk with slit as that illustrated is

called the "Stenopaic" disk or slit, it forms a very valuable aid to diagnose certain conditions of refractive error, its importance is too often overlooked and by many not even understood and used.

Figure 67 shows the stenopaic disk the slit at right angles to the axis of the convex cylinder, the parallel rays now undergo refraction by the principal meridian P M and are brought to a *focus* upon the screen S to a point A. By comparison of the effects illustrated by figures 66 and 67 it is seen that when the stenopaic slit is parallel to the axis of the cylinder it destroys its power, knowing this it is always possible to locate the axis of a cylinder by rotating the disk before it and noting the meridian in which no refraction occurs and objects appear the plainest. The explanation of this phenomena is that the slit cuts out

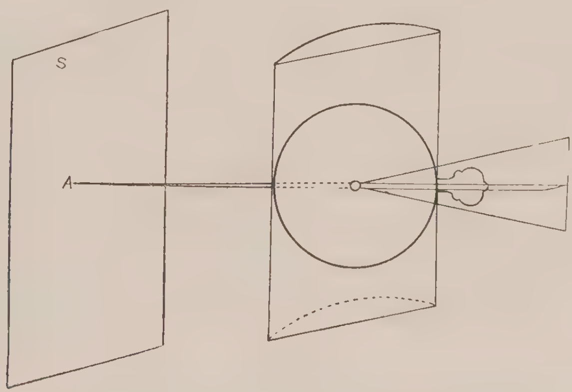

Figure 68.

Light refracted by a convex cylinder, a pin hole disk imposed.

all rays except those in the plane that is parallel to the opening; or another way of stating it is, that it cuts out all the marginal rays except in the one meridian.

Figure 68 represents a convex cylinder before which is imposed an opaque disk having a small round hole in the centre, it is called the "Pin hole disk" and is another exceedingly valuable instrument for purposes of diagnosing refractive errors. By reference to figure 17, illustrating the formation of the image of a candle by a small aperture, it is seen that this gives a similar effect. The cylinder would refract the light upon the screen as a strip but the pin hole cuts out all but a few

of the central rays, and throws a small round spot of light A upon the screen S which is not very bright because of the few rays transmitted. By cutting out all the marginal and nearly all the central rays the refractive power of the lens is destroyed and the image is created by the pin hole alone upon the principles demonstrated by figure 17. It will be recalled that the size of the image created by the aperture varied with the position of the screen but that the image was distinct in all positions. In the same way the pin hole shows the same effects with all kinds of lenses, convex and concave sphericals or cylinders and their combinations. The student should experiment to prove this until it is clear to him; take any kind and power of a lens from the test case, hold it close to the eye and endeavor to see through it, no matter

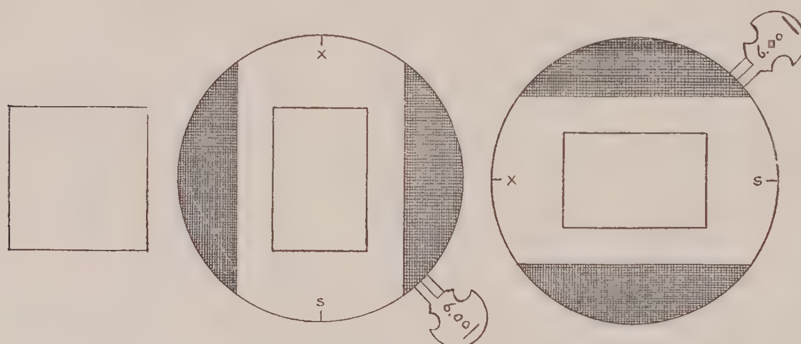

Figure 69.

The distortion of a square figure as seen through a concave cylindrical lens. The sides parallel to the axis appearing the longer and the square becomes a parallelogram.

how indistinct it may make objects appear, when the pin hole disk is imposed, the power of the lens is destroyed and objects are clearly seen.

Whenever a lens possesses unequal curvature in various meridians so that it will not have a real or virtual focus, but refracts light to a line (real or virtual), it is said to be an *astigmatic* and the optical effect produced is called *astigmia or astigmatism.* The name is derived from the word stigma, meaning a point; astigmatic meaning no point or focus

Let I, figure 69 represent a square; II, represents its appearance viewed through a concave cylinder axis vertical. The square becomes a parallelogram, the longer sides being parallel to the axis of the cylinder; III, shows the appearance of the square through the cylinder the

axis being horizontal, now the lengthening of the sides is in a horizontal direction. If a convex cylinder be used to make this experiment, it will be found to distort the square into a parallelogram but in the opposite direction, the sides will be lengthened parallel to the principal meridian and at right angles to the axis.

The cylinder lens illustrated in figure 69, shows one of the customary forms of a lens of this kind used in the test case. The axis is indicated by the marks X and S, while a section of the lens on each side is ground, the boundary of the ground surface being a straight line parallel to the axis.

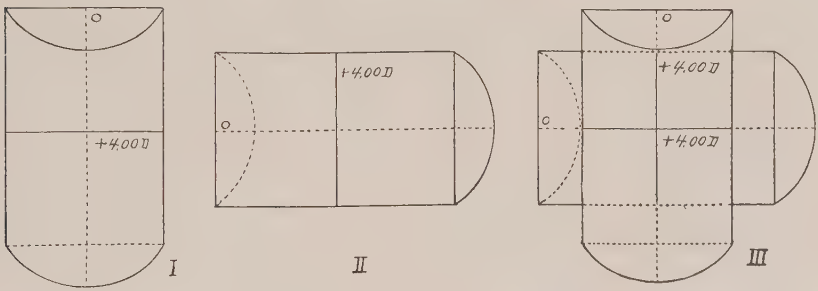

Figure 70.

Two equal convex cylinders, axes at right angles to each other, showing that they are equal to a convex spherical lens.

Figure 70 represents two convex cylinders of equal power, their plano surfaces together and their axes at right angles to each other It will be seen that the principal meridian of each is imposed parallel to the axis of the other; by combining the powers of each of the parallel meridians of these two cylinders it is found that the strength of all are alike, and as this complies with the law governing spherical lenses, the two cross cylinders in this position have a convex spherical value. This makes possible the following law:—

Any two like cylinders of equal power, axes at right angles are equal to a spherical lens of the same power and kind. Any spherical lens may be considered as consisting of two cylinders of like species and equal power whose axes are at right angles.

A clear understanding of this law simplifies calculations in combining lenses of various kinds, in fact any cylinder may be considered as being one half of a spherical lens.

Compound lenses are divided into two classes or species according to the signs indicating the character of the curvatures involved in the make up of the lens. Combinations of lenses having like signs, both plus or both minus, are termed *generic* compounds; while if the signs are not alike, one plus the other minus, they are known as *contra-generic*. Figure 70 represents a generic combination.

Combinations of cylinder lenses are made for the purpose of obtaining certain values in given meridians, it is therefore necessary to adopt some system by which this can be accurately accomplished. The circle with its sub-division into three hundred and sixty degrees was taken as the basis. A horizontal diameter equally divides the circle and beginning at the right hand side it is marked zero (0°), along the circumference upward to the left each five degrees is marked, making the vertical meridian ninety (90°), to the left of the vertical and

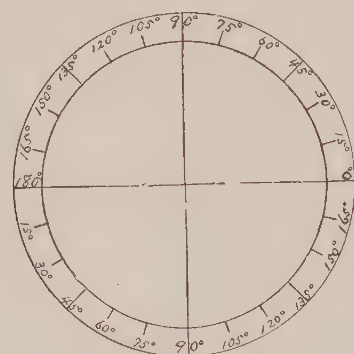

Figure 71.

System for locating the axis of a cylinder in the trial frame.

downward the numbers increase until the horizontal meridian is reached and indicated as one hundred and eighty degrees (180°). Continuing from this point which is also called zero, downward and to the right, the numbers increase until the vertical meridian is reached and marked (90°) ninety degrees and thence around to the starting point which is indicated as one hundred and eighty degrees (180°). The vertical meridian is always indicated as 90°, while the horizontal is called 180°; it might be correctly termed zero, but the other designation is preferred. Figure 71 represents the marking of a trial frame for locating the axis of a cylinder according to the above system. The

reading of the axis indicated by the trial frame is made by the observer as he faces his patient, his line of vision thus meets the outer or anterior surface of the lens. In looking through a lens at the "Protractor scale" the line of vision meets the inner or posterior surface of the lens. This explains the apparent difference in the positions of the numbers of the trial frame scale and the protractor scale. The vertical and horizontal axes read the same on both, but all others seem reversed, thus: Axis 45 degrees on the trial frame appears to be axis 135 degrees on the protractor.

A spherical and a cylinder power may be combined in one lens, in effect it is a combination of a plano-spherical and a plano-cylinder, as the spherical curvature is ground upon one surface and the cylindrical curvature upon the other. The spherical and cylindrical curvature may be ground upon the same surface; such lenses are called "Torus" or "Toric." They have a noticeable curvature, similar to a coquille

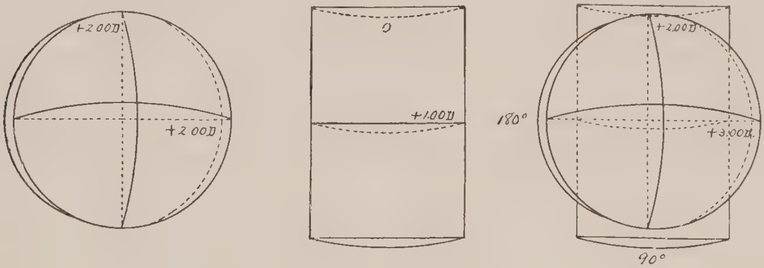

Figure 72.

Plano-convex spherical and plano-convex cylinder combined; showing the power of a generic compound in its principal meridians.

form, and within certain limitations are a decided improvement over the other forms in both appearance and satisfaction to the wearer. They give a wider field of vision and are free from annoying reflection. The thickness of the lens has practically little effect upon the optical value, that is dependent upon the curvature of the surfaces.

Let I, figure 72, represent a plano convex spherical of 2.00 D.; II, represents a plano-convex cylinder of 1.00 D.; III, represents the cylinder in combination with the spherical, its axis at 90°. The formula for this compound will be:

$$+ 2.00 \text{ D. S.} \subset\!\supset + 1.00 \text{ D. Cyl. ax. } 90^\circ$$

and it will be classed as a generic. In the meridian parallel to the axis of the cylinder the power of the combined curvatures will be that

of the spherical alone, while in the meridian parallel to the principal meridian of the cylinder, the power will be that of both the spherical and the cylinder. In the example illustrated by figure 72, the power at axis 90 is + 2.00 D.; at axis 180° + 3.00 D., the cylinder increasing the power of the spherical at this meridian its full strength.

Let figure 73 represent a contra-generic compound, the spherical a concave of 4 00 D., the cylinder a convex of 3.00 D. axis 45°; it should be written:—

—4.00 D. S. ⊃+ 3.00 D. Cyl. ax. 45°.

The power of this combination in the meridian at 45° is — 4.00 D. and

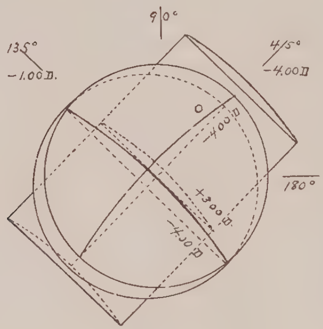

Figure 73.

A contra-generic combination of convex cylinder and concave spherical. At axis 45°, the power of the spherical obtains; at axis 135°. the difference between the spherical and the cylinder.

in the meridian at 135° it is — 1.00 D., it has at least — 1.00 D. power in *every* meridian and this can be subtracted from it, for a — 1.00 D. spherical power exists in the combination. If — 1.00 D.S. be subtracted, in the meridian at 45°, — 3.00 D. remains, while in the meridian at 135° no power remains. The formula for this refractive value is written:—

— 1.00 D. S. ⊃ — 3.00 D. Cyl. ax. 135°

which is a generic compound and is the optical equivalent of the original contra-generic compound

— 4.00 D. S. ⊃ + 3.00 D. Cyl. ax 45°.

From this it will be observed that a contra-generic compound can be turned into a generic. The process of converting a lens formula

from one form into another of equal refractive value is called *transposition.*

The subject of transposition seems always to have been a more or less difficult problem. So many methods may be followed to accomplish the same resuls that they have called for various rules, more or less complicated and difficult to follow, as laid down by various authorities. Transposition is simply a matter of mathematical calculation and is therefore an exact proposition, it is not empirical as many seem to think We may assume that the plano cylinder is the unit and once its principles are understood it is no longer difficult. An endeavor to clear the subject of its mystery and render it as simple as possible will be made.

Transposition means changing the form (curvature) but not the value (dioptric power) of a lens.

A comparison may be drawn between changing money form without altering is value, and transposing form of curvature without altering dioptric power, that will make the subject clear. A dollar bill may be changed into halves, quarters, dimes or pennies; the value of the dollar has not been altered through the change of form. So with a lens; its curvature may be changed into numerous forms, but so long as the relations of these curvatures to each other are undisturbed, its dioptric power remains the same.

The object of transposition is to simplify calculation and reduce the cost of lens making; calculation is less complex with simple formula. If a desired optical effect may be had with a simple and less expensive form of lens, nothing is to be gained by using a more expensive and complicated form. There may be cases in which it is desired to put a simple into a more complex form for certain reasons, as in using torus lenses.

Transposition of spherical formula is simple; it needs no further explanation than that already given in a previous portion of this chapter, that the dioptric power of the spherical (index of refraction of course being the same) depends upon the relation of the curvature of its surfaces. Figure 59 illustrates three forms in which the convex dioptric power is the same. Figure 60 illustrates four forms of concave spherical lens in all of which the dioptric power is the same.

Transposition in which cylindrical power is involved is a little more complicated, but the following theorems once thoroughly understood should enable the student to take up the subject and master it. The rules are simple and may be easily interpreted by the aid of these theorems.

Theorem I.—A. Two generic cylinders of equal power, axes at

right angles, are equal to a spherical of the same dioptric power and species as one of the cylinders.

Examples :

+ 1.00 D. C. Ax. 90° ○ + 1.00 D. C. Ax. 180° = + 1.00 D. S.
— 2.75 D. C. Ax. 140° ○ — 2.75 D. C. Ax. 50° = — 2.75 D. S.
+ 1 50 D. C. Ax. 20 ○ + 1.50 D. C. Ax. 110° = + 1.50 D. S.
— 0.50 D. C. Ax. 10° ○ — 0.50 D. C. Ax. 100° = — 0.50 D. S.

B. Any spherical may be considered as two generic cylinders of equal power, axes at right angles.

Examples :

— 2 00 D S. = — 2.00 D. C Ax. 160° ○ —2.00 D. C. Ax. 70°.
+ 0.75 D. S. = + 0 75 D. C. Ax. 85° ○ + 0 75 D. C. Ax. 175°.
+ 3.50 D. S. = + 3 50 D. C. Ax. 50° ○ + 3.50 D C. Ax. 140°.
+ 1.00 D. S. = + 1.00 D. C. Ax. 115° ○ + 1.00 D. C. Ax 25°.

Theorem II.—A. Two generic cylinders, axes parallel, are equal to one cylinder of the same species whose power is that of the two combined, the axis will be the same as that of the original cylinders.

Examples :

+ 1.25 D. C. Ax. 60° ○ + 0.50 D. C. Ax. 60° = + 1.75 D. C. Ax. 60°.
+ 2.00 D. C. Ax. 25° ○ + 1.50 D. C. Ax. 25° = + 3.50 D.C. Ax. 25°.
— 0.75 D. C. Ax. 165° ○ — 1.25 D. C. Ax. 165° = — 2.00 D. C. Ax. 165°.
— 1.00 D. C. Ax. 30° ○ — 0.75 D. D. Ax. 30° = — 1.75 D. C. Ax. 30°.

B. Any cylinder may be divided into two generic cylinders, axes parallel to the original, whose combined power is equal to that of the original.

Examples :

— 3.00 D. C Ax. 20° = — 1.25 D. C. Ax. 20° ○ — 1.75 D. C. Ax 20°.
+ 1.50 D. C. Ax. 95° = + 1.00 D. C. Ax. 95° ○ + 0 50 D. C. Ax. 95°.
+ 2.50 D. C. Ax. 105° = + 1.75 D. C. Ax. 105° ○ + 0.75 D. C. Ax. 105°.
— 2.00 D. C. Ax. 45° = — 1.00 D. C. Ax. 45° ○ — 1.00 D. C. Ax. 45°.

Theorem III.—Two contra-generic cylinders, axes parallel, are equal to one cylinder of the power represented by the difference between the two, the axis of which will be the same as that of the originals and its sign will be that of the greater. If they are of equal power they are equivalent to a plano glass.

Examples :

$+$ 2.75 D.C. Ax. 90° $\frown$ $-$1.50 D.C. Ax. 90° $=$ $+$ 1.25 D,C. Ax. 90°.
$-$ 3.25 D.C. Ax. 165° $\frown$ $+$1.75 D.C Ax. 1 5° $=$ $-$ 1.50 D.C. Ax. 165°.
$+$ 1.50 D.C. Ax. 90° $\frown$ $-$1.50 D.C. Ax. 90° $=$ Plano.
$-$ 0.75 D.C. Ax. 180° $\frown$ $+$0.75 D.C. Ax. 180° $=$ Plano.

Objective demonstration of transposition is of great assistance ; a simple system of diagrams will be adopted.

As a spherical lens possesses equal dioptric power in every meridian, it may be represented by a diagram consisting of a straight line at any axis crossed at right angles by another straight line.

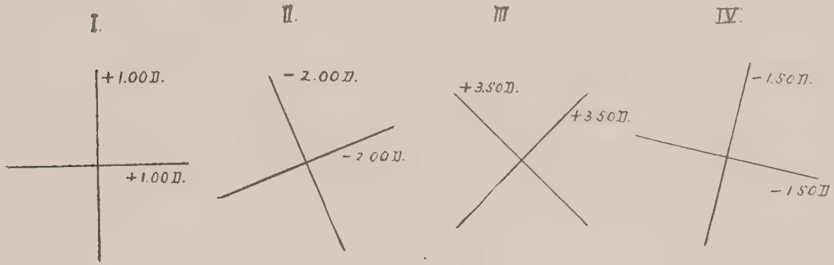

Figure 74.

Diagrammatic representation of spherical lenses. I, represents a $+$ 1.00 D.S.; II, $-$ 2.00 D.S; III, $+$ 3 50 D. S.; IV, $-$ 1.50 D. S.

Figure 74 illustrates spherical values by diagrams. I. represents a $+$ 1.00 D. S.; II. represents a $-$ 2.00 D. S.; II. represents a $+$ 3.50 D. S-; IV. represents a $-$ 1.50 D. S. At the upper and right hand ends of the lines the dioptric power in these meridians is indicated.

A cylindrical lens may be represented by a diagram in which a straight line is parallel to its principal meridian, while at right angles to it and parallel to the axis of the cylinder the straight line is crossed by a dotted straight line. It should be a simple matter to remember this by comparing it to the saying—"united we stand, divided we fall"—the divided or dotted line represents no power (the axis), the unbroken line represents the greatest power (the principal meridian).

Figure 75 illustrates cylinder values by diagrams. At the upper and right hand ends of the lines the dioptric power in these meridians is indicated, while at the lower and left hand ends is

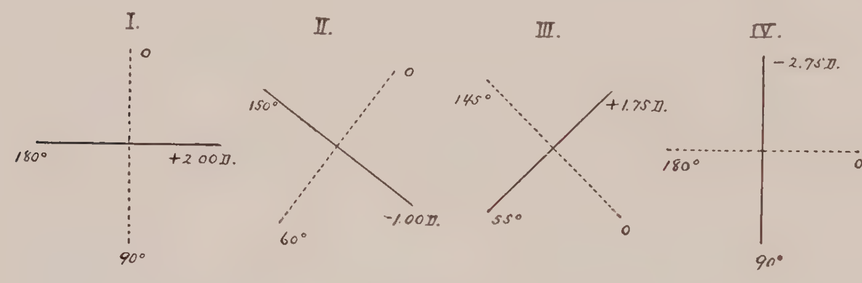

Figure 75.

Diagrammatic representation of cylindrical lenses I, represents a + 2.00 D. C. ax. 90°; II, — 1.00 D. C. ax. ax. 60°; III, + 1.75 D. C. ax. 145°; IV, — 2.75 D. C. ax. 180.° The dotted line indicates the axis and represents no power.

marked the location of the principal meridians. I. represents a + 2.00 D. C. Ax. 90°; II. represents a — 1.00 D. C. Ax. 60°; III. represents a + 1.75 D. C. Ax. 145°; IV. represents a — 2.75 D. C. Ax. 180°.

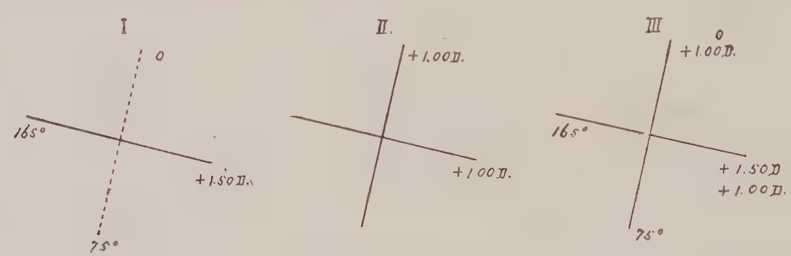

Figure 76.

Diagram to represent a sphero-cylinder. I, represents + 1.50 D. C. ax. 75°; II, + 1.00 D.S.; III, the generic sphero-cylinder.

To represent a sphero-cylinder lens by a diagram, it will be necessary to combine the diagram representing the cylinder with that representing the spherical, just the same as we combine spherical with cylindrical curvature to form the lens. For example, take the following generic compound :

+ 1.00 D. S. ⊃ + 1.50 D. C. Ax. 75°.

First draw a diagram to show the cylinder, I, figure 76; then draw a diagram of the spherical, having the meridians parallel to the principal meridians of the cylinder; II, figure 76. If these were drawn with India ink upon two pieces of glass, and one placed upon the other, they would have the appearance shown by III, figure 76. The unbroken line of the spherical diagram imposed upon the dotted line of the cylinder diagram makes both lines appear unbroken.

+ 0.75 D. S. ⊂ — 2.00 D. C. Ax. 20°.

Draw the diagram of the cylinder first, representing it by two unbroken lines (the dotted line only being used to indicate no power, it is only used with a plano cylinder). Mark the power and the meridians, then indicate the spherical power on the same diagram below that showing the cylinder power, see figure 77.

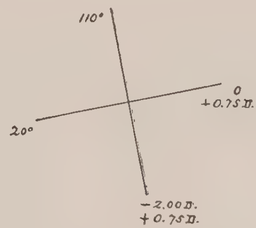

Figure 77.

Diagram to represent a contra-generic sphero-cylinder, + 0.75 D. S. ⊂ — 2.00 D. C. ax.20°

By this method of indicating the powers involved, the value of the combination in the principal meridians may be obtained by combining them. Thus, in figure 77, the power in the meridian at 20° is + 0.75 D., in the meridian at 110° it is — 1.25 D. In figure 76 the power of the combination in the meridian at 75° is + 1.00 D., in the meridian at 165° it is + 2.50 D.

The representation of cross cylinders by diagram will be simply that of two plano-cylinders imposed upon each other; the lines will obviously be unbroken, the marking of the axes and powers will be similar to that of a sphero-cylinder. The following cross cylinder will serve as an example, illustrated by figure 78.

+ 1.00 D. C. ax. 175° ⊂ — 2.75 D. C. ax. 85°.

I, represents the first cylinder, the convex; II, the second cylinder, the concave; III, the cross cylinders.

The following formulae are already in the simplest form. Sphericals, plano cylinders, generic sphero cylinders, and contra-generic sphero-cylinders in which the cylinder is the greater.

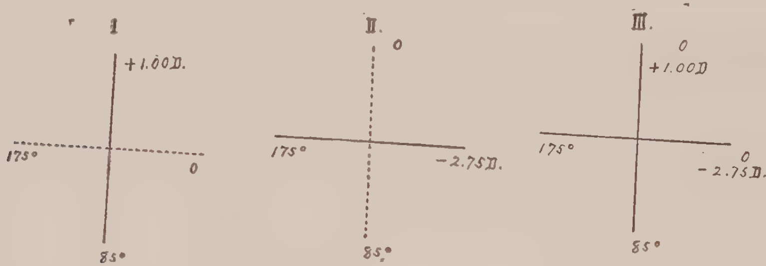

Figure 78.

Diagram to represent cross cylinders. I, represents the convex cylinder; II, the concave; III, the combination of the two.

A contra-generic sphero cylinder, in which the spherical power is greater than that of the cylinder, may be reduced to a generic compound by the following rule.

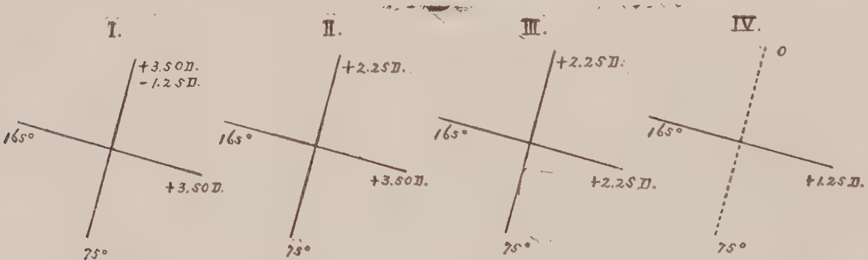

Figure 79.

Diagram to represent transposition of a contra-generic sphero-cylinder into its equivalent generic sphero-cylinder.

Rule I.—*Subtract the power of the cylinder from that of the spherical, the remainder will be the power of the new spherical; the power of the cylinder remains the same, but its sign changes and its axis will be at right angles to its former position.*

A short method of locating the new axis is to add 90° if the original is less than 90°, or subtract 90° if the original is more than 90°.

Example:—

$$\begin{array}{l} +\ 3.50 \text{ D. S.} \bigcirc -\ 1.25 \text{ D. C. ax. } 165^\circ \\ -\ 1.25 \qquad\qquad\qquad\qquad\qquad\qquad 90^\circ \\ \hline +\ 2.25 \text{ D. S.} \bigcirc +\ 1.25 \text{ D. C. ax. } 75^\circ \end{array}$$

To represent this by diagram let I, figure 79, illustrate the original contra-generic sphero cylinder; II, figure 79 will represent the equivalent generic sphero-cylinder which may be divided into its component spherical and cylinder which are shown by III and IV, figure 79.

A contra-generic sphero-cylinder in which the powers are equal, may be reduced to a plano-cylinder by the following rule.

Rule II.—*Arbitrarily change the sign of the cylinder and locate its axis at right angles to its former position, the same as in rule I. Drop the spherical.*

Example:—

$$\begin{array}{r} +\ 1.50 \text{ D. S.} \bigcirc -\ 1.50 \text{ D. C. ax. } 180^\circ \\ 90^\circ \\ \hline +\ 1.50 \text{ D. C. ax. } 90^\circ \end{array}$$

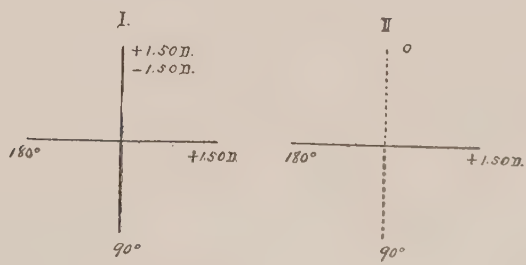

Figure 80.

Diagram to represent transposition of a contra-generic sphero-cylinder into its equivalent plano cylinder.

Figure 80, will show by diagrams how this is done, I, represents the sphero-cylinder; II, represents the plano-cylinder resulting from the combination.

Any cross cylinder may be transposed into its equivalent sphero-cylinder by the following rule.

Rule III.—*Take either cylinder for the spherical. Add the powers of the two cylinders to obtain the power of the new cylinder, its axis and sign will*

be the same as the original cylinder that was not converted into the spherical.

Example:—

— 1.00 D. C. ax. 180° ⊂ + 1.50 D. C. ax. 90°
1.00 D. C.

— 1.00 D. S. ⊂ + 2.50 D. C. ax. 90°

or the other cylinder be made the spherical, thus:—

— 1.00 D. C. ax. 180° ⊂ + 1.50 D. C. ax. 90°
1.50 D. C.

— 2.50 D. C. ax. 180° ⊂ + 1.50 D. S.

This may be represented by diagram; let I, figure 81 represent the cross cylinders. If it is desired to make the convex cylinder the

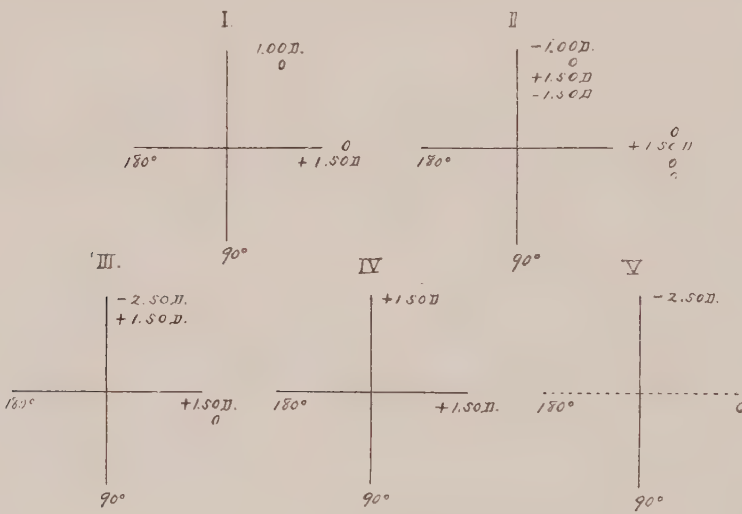

Figure 81.

Diagram to represent transposition of cross cylinder into its equivalent sphero-cylinder.

spherical it will be necessary to add + 1.50 D. in the meridian at 90°, which is a + 150 D.C. ax. 180°, this is shown in II, figure 81. Now the addition of this + 1.50 D. in the meridian of 90° reduces the original so that it must be increased by a like amount to offset it. We therefore add — 1.50 D. in the meridian at 90°, which is — 1.50 D. C. ax. 180° and is shown in II, figure 81. Combine these powers in the two

meridians and we have what is represented by III, figure 81. This may be split into its component parts shown in IV and V, figure 81.

Any sphero cylinder may be transposed into its equivalent cross cylinder by the following rules. If it be a generic:—

Rule IV.—*The spherical becomes a cylinder without change of sign, its axis will be at right angles to that of the original cylinder. The power of the other cylinder will be that of the original cylinder and the spherical combined, its sign and axis will be the same as the original cylinder.*

If the sphero-cylinder be a contra generic, in which the cylinder is greater than the spherical:—

Rule V.—*The spherical becomes a cylinder without change of sign, its axis will be at right angles to that of the original cylinder. The power of the other cylinder will be the difference between the powers of the spherical and original cylinder, its sign and axis will be the same as the original cylinder.*

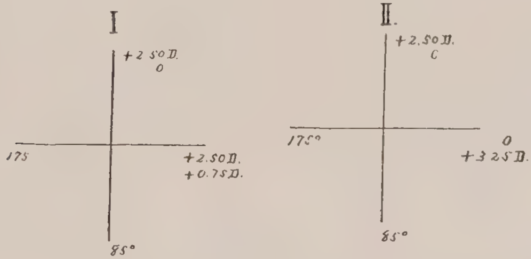

Figure 82.

Diagram to represent transposition of a sphero-cylinder into its equivalent cross cylinder.

If the sphero-cylinder be a contra-generic in which the spherical is the greater, reduce it by Rule I to a generic and then by Rule IV to a cross cylinder.

Example, Rule IV:—

$$\begin{array}{c} +\ 2.50\ \text{D. S.} \supset +\ 0.75\ \text{D. C. ax. } 85^\circ \\ 2.50 \\ \hline +\ 2.50\ \text{D. C. ax. } 175^\circ \supset +\ 3.25\ \text{D. C. ax. } 85^\circ \end{array}$$

This may be readily explained by reference to theorem I, B; divide the spherical into its equivalent cross cylinders and we have

$+\ 2.50$ D. C. ax. $175^\circ \supset +\ 2.50$ D. C. ax. $85^\circ \supset +\ 0.75$ D. C. ax. 85°

on combining the two parallel generic cylinders we have the result given above.

By diagram we may represent the transposition in figure 82; I, shows the sphero-cylinder; II, the cross-cylinder.

Example, Rule V:—

$$+1.25\text{ D. S} \supset -2.75\text{ D. C. ax. }40^\circ$$
$$1.25$$
$$\overline{+1.25\text{ D. C. ax. }130^\circ \supset -1.50\text{ D. C. ax. }40^\circ}$$

Divide the spherical into its equivalent cross cylinders as above

$$+1.25\text{ D. C. ax. }130^\circ \supset +1.25\text{ D. C. ax. }40^\circ \supset -2.75\text{ D. C. ax. }40^\circ$$

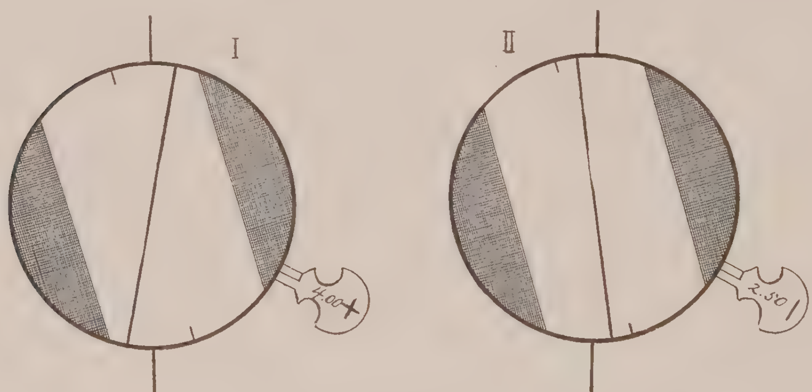

Figure 83.

The broken appearance of a vertical straight line seen through a plano-cylinder lens rotated upon its optical centre. I, a convex; II, a concave cylinder.

and then combine the parallel contra-generic cylinder, the above result will be obtained. A diagrammatic representation is unnecessary.

In experiment illustrated by figure 50, it was found that upon rotating a spherical lens, a vertical straight line seen through it was not distorted; this property serving as one of the means of identifying a spherical. If the same experiment be made with a cylindrical lens, the line will appear to break at the edges of the lens and to oscillate, swinging to a certain distance and then back again. Figure 83 will illustrate the effect created; I, shows the appearance of the vertical straight line seen through a convex cylinder; II, the same line seen through a concave cylinder. Comparison shows that the direction of

the motion of oscillation is the reverse with a convex to what it is with a concave. In making this experiment it will be noticed that in two positions, as the lens is rotated, the vertical straight line will appear unbroken as seen by A and B, figure 84. This applies to both convex and concave cylinders, no difference in them will be detected if each be placed in these positions.

In the illustrations the cylindrical lenses shown are purposely taken from the test cases, to make it as easy as possible for the student to understand; their action is exactly the same as other similar lenses.

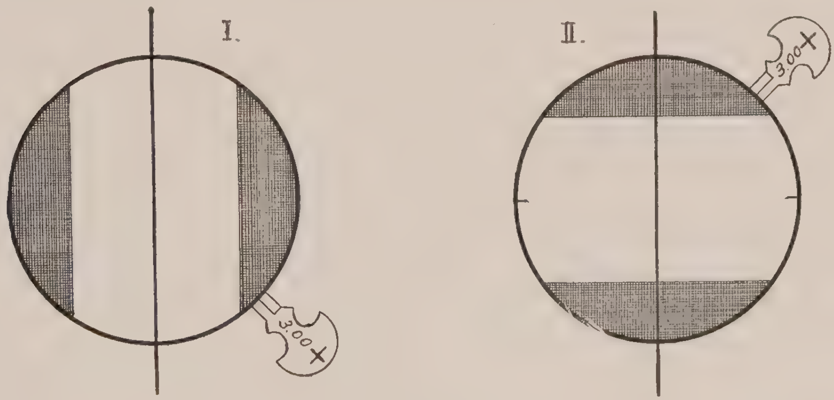

Figure 84.

Unbroken appearance of a vertical straight line seen through a cylinder lens in two certain positions. The cylinder may be either convex or concave.

Mark with india ink at the edge of the lens the four points through which the line appears to pass, unbroken, this procedure being similar to that in experiment illustrated by figure 47. It will be found that these points are 90° apart, that if opposite points be joined by straight lines, these lines will cross each other at right angles. If they do not, erase them and try again for this is the proof that the points are correctly located.

These two lines will indicate the two principal meridians of the cylinder, and their point of intersection will be its optical centre.

This experiment serves a double purpose, by means of it we can identify a cylinder and locate its principal meridians. The next point is to determine which of these is the principal meridian and which the

axis. Rotate the plane cylinder to a position in which the vertical straight line appears through it unbroken; by reference to II, figure 48 the effect desired will be seen, the line passing through two of the points marked upon the lens. With the lens in this position repeat experiment illustrated by figure 48. If the motion of the lens to the right and left causes the portion of the lens seen through it to move, breaking and causing its displacement, refraction must take place in this meridian. Knowing that no refraction occurs in the axis of a cylinder, this meridian must be the principal meridian. Connect the two points marked upon the lens that are in the vertical plane, when the lens is in this position, with a line of dots marked with the india ink, see figure 85, *this will be the axis.*

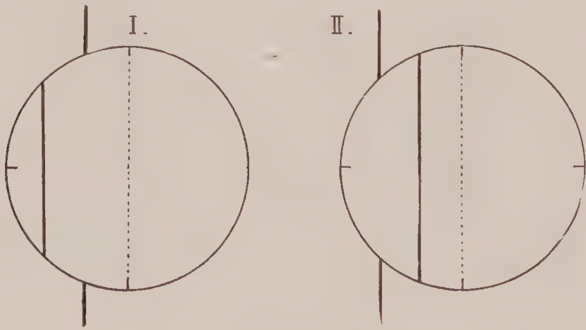

Figure 85.
Displacement of a vertical straight line by a cylinder lens, its axis parallel to the line. I, a convex; II, a concave.

If the motion of the object seen through the lens be opposite or *against* that of the lens, the cylinder is convex, the appearance created is shown by I, figure 85. If the motion of the object viewed through the lens be the same as that of the lens, or *with* it, the cylinder is a concave and II, figure 85 illustrates the effect.

Now rotate the lens 90°, so that the vertical straight line also appears unbroken and passing through the other two points; move the lens to the right and left as before and the line as seen through it will not appear to move. No refraction occurs in this meridian and this indicates the axis. Figure 86 illustrates this experiment, no matter if the cylinder be convex or concave, so long as the dotted line remains

at right angles to the vertical line, no distortion or displacement takes place. The effect optically is that of plano glass. These experiments demonstrate the fact that the power of a cylinder is at right angles to its axis.

The characteristics of a plano cylinder lens may be summarized in a few words as follows:—

First:—Upon rotating it, objects seen through it appear distorted.

Second:—In two positions a vertical straight line appears through it unbroken, in each position the line is parallel to one of its principal meridians.

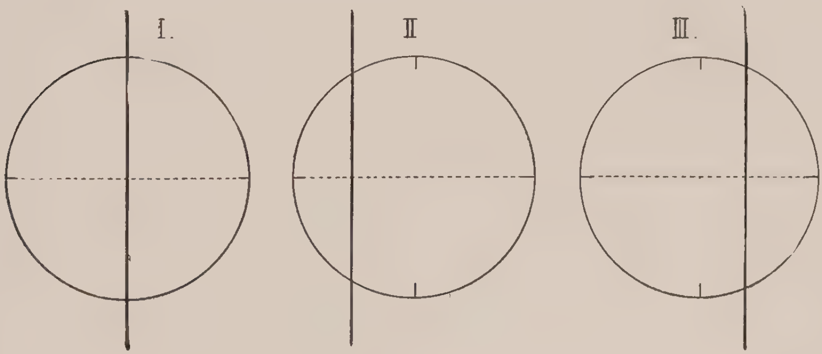

Figure 86.

A vertical straight line seen through various portions of a plano-cylinder lens its axis at right angles to the line. The cylinder may be either convex or concave.

Third:—Motion occurs at right angles to one of these meridians which is the axis.

Fourth:—If the motion of the object seen through it is against that of the lens, the cylinder is convex; if it is concave the motion will be with that of the lens

If a vertical straight line be viewed through a prism whose base line is at right angles to it, the line will appear unbroken, no matter through what portion of the prism it is seen; see II, Figure 87. If the base line of the prism be parallel to the line it will appear broken, that portion of the line seen through the prism being displaced toward the apex of the prism; see I, Figure 87. The amount of displacement

is the same regardless of the portion of the prism through which the line is seen.

If a prism be combined with a spherical, cylinder or sphero-cylinder lens, the dioptric properties of the spherical, cylinder or sphero-cylinder remain unaltered except that the prismatic displacement occurs with the other optical characteristics of the lens. To prove this take any convex spherical lens from the test case, preferably a high power (say + 14.00 D), because it cr ates a small image, and

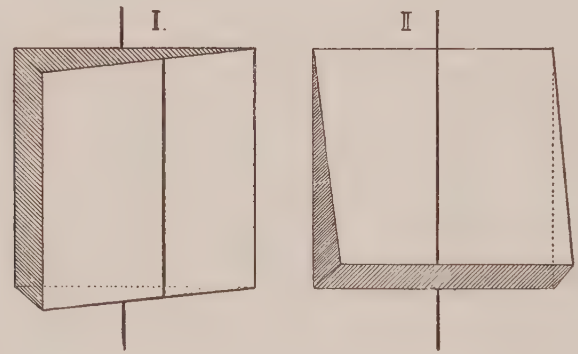

Figure 87.

Showing prismatic displacement.

focus an image upon a white cardboard screen of some object; the picture presented through a window is always convenient. Having obtained a clear sharp image impose a prism before the spherical and in contact with it, the image will instantly be displaced but it will still be sharp and clear, showing that the focal power of the spherical has not been disturbed.

It may be a bit confusing to the student to find that the image is displaced toward the base of the prism in making the above experiment, but if he will stop to think a moment he will understand that this is correct. In looking at an object through a prism, the object appears displaced toward the apex, because the light rays coming from the object to form the image are refracted toward the base of the prism, and the displacement of the image is therefore toward the base.

Figure 88 represents cross sections through a convex sphero-prism and a concave sphero-prism.

If a prism be combined with a cylindrical lens, the base line of the prism being at right angles to the axis of the cylinder, the effect in the direction of the line of the axis is that of the prism combined with a plano glass, practically that of the prism alone. If in combination with a cylindrical lens the base line of the prism is parallel to the axis of the cylinder, the effect is that of the cylinder with the prismatic displacement. From the foregoing it should not be difficult to see the effect of a sphero cylinder prism.

Referring to figures 36 and 53 it is seen that convex spherical lenses are in effect two prisms base to base, while concave spherical lenses are two prisms their apices together. Any ray except that

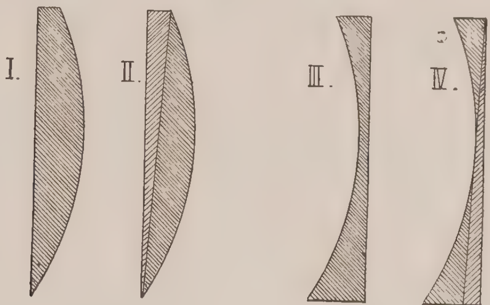

Figure 88.

Cross sections of sphero-prisms.

passing through the optical centre of a spherical lens is subjected to prismatic action; any portion of such a lens except the optical centre therefore possesses prismatic as well as dioptric power.

The importance of properly centering lenses is thus demonstrated unless it is desired to combine prismatic with dioptric value. To obtain this combination in any lens it is simply necessary to cut the lens so that its optic centre is displaced from its geometric centre in a certain direction and to a definite amount, or to "decentre" the lens as it is termed. See figure 52.

If power of a certain kind is obtained by decentration it is obviously necessary to follow some method.

Prisms are now numbered in what are termed prism-dioptres. According to this system a one degree prism at a distance of one metre (40 inches or one dioptre) creates an optical displacement of ten millimeters. A one dioptre spherical lens decentred ten millimeters is equivalent to a one degree prism combined with the spherical. As a spherical has equal power in every meridian the prism value will be the same if the lens is decentred in any direction. From the above the following rule may be adopted.

A decentration of ten millimeters gives as many degrees of prismatic power as the lens possesses of dioptric power

Examples :

Dioptres.	Millimeters decentred.	Value.
+ 1.00	10	+ 1 00 D $\bigcirc$ 1° Prs.
— 1.00	10	— 1 00 D $\bigcirc$ 1° Prs.
+ 2.50	10	+ 2.50 D. $\bigcirc$ 2.5° Prs.
— 4.00	5	— 4.00 D. $\bigcirc$ 2° Prs.
+ 5.00	1	+ 5 00 D $\bigcirc$ 5° Prs.
+ 2.50	4	+ 2.50 D. $\bigcirc$ 1° Prs.

A short method to ascertain the amount of decentration required of any lens to obtain a given prismatic value is to multiply the number 10 by the prism degree required and divide the result by the dioptric power of the lens.

Examples:

Prism.	Dioptres.	Millimeters.
2°	3 D.	$10 \times 2 = 20 \div 3 = 6\frac{2}{3}$
1°	4 D.	$10 \times 1 = 10 \div 4 = 2\frac{1}{2}$
$1\frac{1}{2}$°	5 D.	$10 \times 1\frac{1}{2} = 15 \div 5 = 3$
$2\frac{1}{2}$°	6 D.	$10 \times 2\frac{1}{2} = 30 \div 6 = 5$
4°	2 D.	$10 \times 4 = 40 \div 2 = 20$

Theoretically there is no limit to the amount of decentration but in practice it is not possible to obtain decentration to a large amount owing to the limitations of the size of the "uncut lenses." Reference to Figure 52 shows a lens of 33x37 millimeters to be made from an uncut lens about 45 millimeters square. By applying a rule to the drawing it will be seen that it will be possible to decentre the lens only about 4 millimeters in one direction or about 6 millimeters in the other. It will thus be seen that where the desired lens is large the amount of decentration possible will be small; also, that where the dioptric power is weak, but little prismatic effect may be obtained by decentration within the limits of the average uncut lens.

The writer has often been asked by students—"Is it just the same when you decentre a lens to get a prism effect as if the prism were ordered ground with the spherical?"—the impression being that there must be some difference. To clear this point it may be stated that there is no difference, all prismatic power is the same, only differing in degree.

The statement has been made that a spherical lens may be decentred in any direction with equal effect, but this cannot be true of a cylindrical lens because of its unequal power in various meridians. Decentration in the direction of the axis creates *no* prismatic effect; along a line at right angles to the axis, the amount of prism developed will be the same as if the cylinder were a spherical. Decentration along any intermediate meridian will develop prism power proportional to the dioptric power through that meridian. Reference back to the subject illustrated by figure 64 will make this plain.

Estimation for decentration of sphero-cylinders need not be made difficult, the spherical and the cylinder may be considered separately and then combined, but taken together it is not a complex operation. A few points only are involved.

If the decentration is parallel to the axis, only the value of the spherical is involved, no matter if the sphero cylinder be generic or contra-generic.

If the decentration be at right angles to the axis and the lens is a generic compound, the dioptric power involved is the full amount of the spherical and the cylinder combined.

If the decentration be at right angles to the axis and the lens is a contra generic, the dioptric power available for prismatic effect is the difference between the spherical and the cylinder.

If the decentration be in a direction other than parallel to, or at right angles to the axis, estimate the power of the cylinder in this meridian and add it to the spherical if the compound be a generic, or subtract it if the compound is a contra-generic.

The subject of neutralizing lenses has practically been covered in this chapter. The student has learned all the difficult points. The recognition of spherical lenses, and the determination if convex or concave is understood. Cylindrical lenses, the location of their axes and determination of species has been explained. Sphero cylinders and their characteristics; prisms, simple and in combination have been explained and the student who has faithfully followed up the

work so far outlined need fear no difficulty in recognizing any kind of lens. The only point yet unexplained is the determination of the exact dioptric value of an unknown lens.

The treatment of the subject will be taken up merely in the form of a review which will include this last point, the procedure to determine the character and power or powers of an unknown lens will be given.

To neutralize means to destroy power. It is inferred that a certain power or property is possessed by something when the term neutralize is used, to which by the act of neutralizing, is opposed a similar power or property that counterbalances its action. To neutralize is thus to oppose power of a certain kind with similar power operating in an opposite manner so that both are destroyed.

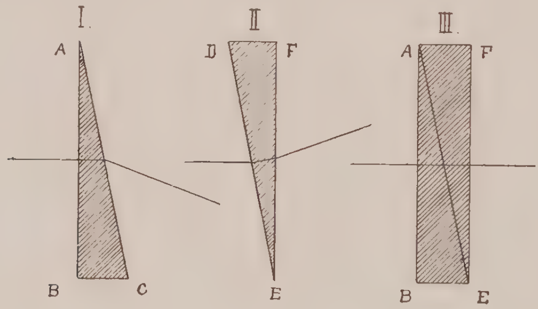

Figure 89.
Neutralizing prisms.

In optics we have lenses that possess directly opposite powers, creating opposite effects, viz:—those lenses that converge light rays and those that cause them to diverge.

To neutralize optically we oppose convex and concave power and destroy both, the effect being that of plano glass. To demonstrate the theory of neutralizing let figure 89 represent two prisms of equal power and similar form. If they should be imposed base to apex, it will be seen by reference to III, figure 89, that a cross section through would show the surfaces A. B. and F. E. to be parallel and therefore the optical effect would be that of plano glass. The refractive power of each is destroyed by so opposing their powers. To prove this by

experiment take a prism of any power and look through it at a vertical straight line, holding the prism as shown by I, figure 87, the line will appear broken. If a prism of equal strength be now imposed the line will assume its unbroken appearance.

To follow this line of investigation further, suppose a plano-convex lens and a plano-concave lens of the same index of refraction and the same radius of curvature be imposed with their curved surfaces in contact. By reference to figure 90 it will be seen that one fits exactly into the other; t e refractive value is then the same as plano glass. The converging power of the convex is neutralized by the diverging power of the concave.

I. II. III.

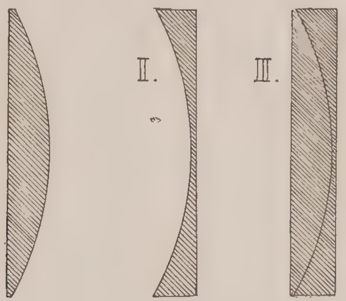

Figure 90.

Neutralizing spherical lenses.

An ocular demonstration of this may be made by repeating experiment illustrated by figure 48, using a convex and concave spherical of the same dioptric power, the lenses being selected from the test case. The movement created by the convex lens will be against that of the lens, while the movement created by the concave will be with that of the lens. *When they are imposed and there is perfect neutralization no movement will be manifest.*

In the same way a convex and a concave cylinder lens of the same dioptric value neutralize when they are imposed with their *axes parallel.*

The following is a simple procedure to neutralize lenses in a scientific manner. Hold the lens with both hands and rotate it as described and illustrated by figure 50; if no distortion occurs it is a spherical.

If it is determined that the lens is a spherical, move it laterally with a pendulum like motion as illustrated by figures 48 and 57, and neutralize with a spherical of the opposite kind.

If on rotating the lens distortion is manifest, the lens is either a sphero cylinder or a plano cylinder (possibly a cross cylinder). The fact that distortion occurs betrays the presence of cylindrical power in the lens. Locate the principal meridians and determine if it is a plano-cylinder; if it proves to be a cylinder neutralize it with a cylinder of the opposite kind, placing the axes parallel.

If the lens is found to be a sphero cylinder determine if it is a generic compound, which will be the case if the motion created is the same in both principal meridians; that is, against the motion of the lens in both meridians, or with the motion of the lens in both.

If the lens is a generic sphero-cylinder, neutralize the meridian of least power first with a spherical; this will represent the spherical power of the unknown lens. Now turn the lens at right angles and neutralize the other principal meridian which will be the cylinder.

If the lens is found to be a contra-generic sphero-cylinder, as will be manifest by the fact that the movement in one of the principal meridians is with and in the other against the movement of the lens, it will be necessary to determine upon which surface the cylindrical is ground. If the cylindrical is of high power there will be no difficulty in recognizing it; if it be of low power it wili be difficult to recognize it by the appearance of the surface. A lens measure will be the simplest way to determine the point or a straight edge placed in contact with the surfaces will show which surface is the cylindrical. Having determined whether the spherical is plus or minus, neutralize the spherical first and then the cylindrical.

Prismatic displacement is neutralized by placing a known power prism in opposition to the unknown so that no displacement occurs.

CHAPTER III.

PHYSICAL OPTICS.

THE student may be inclined to think by this time that the study of optics is a "dry and u interesting grind," basing his opinion upon the matter contained in the preceding chapter. It is the foundation upon which his optical knowledge must be built and the measure of his success will be in direct proportion to his ability to calculate lens formulas. A thorough knowledge of the properties and application of lenses is absolutely necessary to secure proficiency in higher optics. Education is not a commodity to be purchased; it must be secured by individual effort; every man must obtain it by his own work. There is no royal road to optical knowledge any more than there is to any other. We see men who have had exactly the same opportunities in the same college accomplishing far different results. Is it not due to their individual efforts? If a man is mentally lacking in capacity for certain work, or it is not congenial to him, it is better he should turn his talents in another direction for which he may be fitted. A certain amount of mathematical knowledge is required in the practice of applied optics and unless the preceding subjects can be mastered the student had better attempt to go no further. Encouragement may be held out to him, however, by stating that the "dry" portion of the study has been passed, that which follows will hold his attention because the experiments will prove interesting.

Physiological Optics may be more intelligently studied if the student be familiar with Physical Optics. The living eye cannot be dismembered that its errors may be determined and their correction supplied, but mechanical optical instruments of man's construction may be taken apart and their constituents separately considered. We may also take the various lenses we have been studying and construct devices that nearly approach, mechanically, the functions performed by the eye under normal conditions. Abnormal conditions may also be created in the same way; their effects may be noted; their correction may be estimated and applied. Equipped with the knowledge thus obtained, the student is prepared to take up the deeper subject of Physiological Optics

That portion of Physical Optics with which the student must become familiar is that which relates to the formation of real images by lenses. It is repetition, but the subject is of sufficient importance to bear repeating, to state that *a real optical image is one that may be received upon a screen. It is created by a convex spherical lens which brings the rays of light from every point upon the object to a focus, and a screen placed at the exact focal point of the lens will receive the image.*

It has been demonstrated that of the various forms of lens, only convex spherical lenses are capable of creating real images; also, that they possess two faults that seriously interfere with the formation of correct images, viz:—spherical and chromatic aberration. To overcome these defects and make possible the creation of perfect images that are geometrically correct pictures, it is necessary to resort to various devices; these are called *refracting systems.*

The simplest form of a refracting system consists of a convex spherical lens with a diaphragm. A diaphragm for a refracting system is usually a metal disk having a round hole so situated in the disk that its centre corresponds to the optical centre of the lens and placed in such position, with regard to the lens, that it permits only the light rays that pass through the central portion of the lens to reach the screen. By reference to figure 44 it will be seen that if such a diaphragm were placed behind the lens, the rays that pass through the marginal portion of the lens, and have their focus at G, would be cut out, and if a screen were placed at F, a sharp, clear image would be created. This is not an absolute correction for the spherical aberration but for the purposes of this book it goes far enough in explanation.

Referring to experiment illustrated by figure 58 we found that light undergoing refraction was *dispersed*, due to the difference of the degree of deviation of the various rays. Those rays forming the red end of the spectrum being the least refrangible, those at the violet end being the most refrangible. We have learned that the index of refraction varies for different substances, and this is also true of glass of different compositions.

The index of refraction and the power of dispersion for all kinds of glass are not proportional, and because of this fortunate condition it is possible to construct a refracting system that is corrected for chromatic aberration or is *achromatic*.

An achromatic lens consists of a convex spherical of high refracting power with low dispersion, combined with a concave spherical of low refracting power and high dispersion. In the perfect achromatic

the amount of dispersion of the two lenses forming the combination is equal, but being of contra generic character, or opposite kind, they neutralize. The refracting power of the convex being greater than that of the concave, the convex predominates, being only partially neutralized, thus giving convex spherical power free from chromatic aberration. Now by the addition of a suitable diaphragm, a refracting system that is corrected for both spherical and chromatic aberration is obtained.

These topics of aberration in lenses may seem irrelevant to the study of ocular refraction, but when the subject of Retinoscopy is reached it will be found that they have an important bearing upon the subject. In order that a clear understanding of the formation of real images may be had, the student is urged to make at least all the experiments given and as many more as may be suggested by his own observations. The greatest handicap to a complete and thorough knowledge of refraction has been that there was too much theory taught and too little demonstration. The mind has been taxed with theoretical practice while the eye and the hand have not been trained to apply it.

Figure 2 represented a simple scheme to demonstrate that light travels in straight lines always; an ordinary cigar box, through a little ingenuity, serving all the purposes of more elaborate apparatus.

Procure a similar cigar box and remove the top and one end. In the centre of the other end cut a hole one and a quarter inches in diameter, taking care to make it even and round. The lenses in the average test cases now in use are one and a half inches in diameter; if two pins are driven an eighth of an inch from the edge of the hole toward the bottom, a lens from the test case resting upon them will have its optical centre at the centre of the hole. Bend the pins upward and cut a portion off, leaving them in the form of two small hooks upon which the lenses may be placed without danger of falling out of position. Make two similar hooks of pins on the inner side of the hole, thus, a lens may be placed upon either or both sides of the aperture in the end of the box.

Take a small block of wood about half an inch wide and a little less in length than the width of the box, cut a slot in it in the direction of its length and parallel to the edges of the block. In this slot insert a piece of white cardboard similar to those used in experiment illustrated by figure 2. This will form a screen to receive the image and should be free to slide back and forth easily in the box. For convenience the bottom of the box may be marked off in inches along

its length, beginning at the end where the lenses are placed.

Take a + 8.00 dioptre lens and place it in position on the pins before the aperture, move the screen to a point five inches from the lens and direct the aperture toward a window. A picture (image) will appear upon the screen. Move the screen nearer to the lens, the picture blurs, *it is out of focus because the screen is nearer to the lens than the focal point.* Move the screen more than five inches away from the lens; again the picture blurs, *the screen is beyond the focal point.*

If the same experiment is made with a + 10.00 dioptre lens, the screen must be placed four inches away to obtain a clear picture, with a + 5.00 dioptre lens, eight inches away. *It is thus demonstrated that to obtain a clear image the screen must be situated at the focal point of the refracting system.* If a diaphragm is placed back of the lens it will be found that while the image is not so bright, that it is more sharply defined.

The student will notice that the image created by the ten dioptre lens is smaller than that created by the eight or the five dioptre lens.

The greater the power of the refracting system, the smaller will be the image created by it.

It is of the most importance that the optical student should understand this difference in size of the images of the same object created by lenses, or refracting systems, of different power. It explains the inability to accept a full correction for the error of refraction in a pair of eyes in which there is a marked difference in the refraction. It also explain why it is frequent to find in such cases that vision in one eye is much poorer than the other.

Too much experimental work, along the lines given in this chapter, cannot be done.

Another and more important series of experiments will now be given. Move the screen to ten inches from the aperture and place a + 2.00 D. lens before it, the image formed upon the screen will be much blurred. Add a + 1.00 D. lens and the image will appear more clearly defined, but still far from perfect; upon adding a + 2.00 D. lens to the original it will be found that the image is now clear. Substitute for the two + 2.00 D. lenses a + 4.00 D. lens and the image will appear the same as though created by the two + 2.00 D. lenses combined. Move the screen to five inches from the aperture and place a + 5.00 D. lens before it, the image will not be clear. Trying the addition of convex lenses it will be found that a + 3.00 D. will be required to make the image clear.

With the screen placed four inches from the aperture and a + 8.00 D. lens, + 2.00 D. must be added.

If the screen be located ten inches from the aperture and a + 5.00 D. placed before it, the image will be blurred; the addition of convex lenses renders the image less distinct. By adding a − 1.00 D lens the image will be rendered clear and sharp. Place the screen at eight inches, and using a + 8.00 D. lens, it will be found necessary to add a — 3.00 D. lens in order to obtain a clear image. In making these experiments then, if it is found that the image is blurred or indistinct, add a *convex spherical lens first;* if this is found to improve the image it proves that more refraction is required. If the addition of convex lenses make the image less distinct *concave spherical lenses* are indicated to neutralize a portion of the refraction.

From the above the following rules may be given :

If the screen is too near the refracting system a convex lens must be added to create a clear image.

If the screen is too far from the refracting system a concave lens must be added to create a clear image.

Suppose a + 6.50 D. lens be placed at the aperture and the screen moved to the proper position to secure a clear image, the lens may be rotated about its optic axis without in any way affecting the image ; in fact, while the lens is in motion no change or movement will appear in the image. This experiment may be repeated with any power lens, the result will be the same, thus :

Any convex spherical lens, located at the proper point to create a distinct image, may be rotated, without otherwise altering its position with regard to the screen, and the rotation will not affect the image because of the equal refractive power of the lens in every meridian.

The device used in the above experiments is in effect a rude camera. One of the most valuable aids to the study of physical and physiological optics is the camera obscura. They may be obtained at a small cost, about a dollar each. By moving the lens in the focusing tube, an out of focus condition may be created, which may be corrected by imposing the necessary convex or concave spherical lens. In the camera obscura the image is formed upon the ground glass on the top, the light rays being reflected from a horizontal to a vertical direction by a mirror placed at an angle of forty-five degrees. This renders observation of the image more convenient.

If the device described in the previous experiments be used to focus the rays from a distant luminous point, the following phenomena will be noticed. When the screen is situated at the principal

focus of the refracting system, the light from the luminous point will be focused to a *point* upon the screen. If the screen be moved toward the refracting system, the *point* will take the form of a *circle of diffused light* upon the screen, which will increase in size the nearer the screen is approached to the refracting system. If the screen, being located at the principal focus, is moved away from the refracting system, the point will also assume the form of a *circle of diffused light* upon the screen, which will increase in size the further the screen is removed.

From the foregoing experiments it has been demonstrated that:

Provided convex spherical curvature exists a focus is obtainable, and an image may be created, by locating the screen at the focal point of the system.

In Chapter II. on lenses it was explained that a cylinder lens, having no focus, could not create an image.

Repeat the last experiment given, using a + 8.00 D. spherical and a + 4.00 D. cylinder in combination. The image of the luminous point upon the screen will not be a point. If the axis of the cylinder is in the horizontal plane and the screen is placed close to the refracting system, the circle of diffusion shown in the previous experiment will be replaced with an oval spot of light in which the longest diameter is in the horizontal direction. As the screen is moved away from the system, the oval becomes first a horizontal streak of light, then a vertical streak and finally an oval spot in which the longest diameter is in the vertical direction.

If the axis of the cylinder should be placed in the vertical plane, and the screen located close to the system, the oval of light will appear with the longest diameter in the vertical direction. Upon moving the screen away the streak will first appear vertical, then horizontal and afterwards change to an oval spot having the longest diameter horizontal.

These experiments with sphero-cylinder lenses show that the image, if such it may be called, is distorted and blurred, therefore :

When unequal curvature exists no focus is obtainable, and no image will be created, no matter what the location of the screen.

It has been demonstrated, and the student by this time is doubtless sure, that a spherical lens possesses equal refracting power in every meridian. If some method can be devised to determine if any given refracting system does possess equal refraction, and therefore curvature in every meridian, such determination being based upon an ocular demonstration by which it will be possible *to actually*

see the effect created, it will readily be understood how important it would be.

To accomplish this the familiar clock dial geometrical figure was devised, also the fan dial, which is one half of the clock dial. These are known as *astigmatic test charts.*

In these charts the series of three parallel lines radiate from a centre; the lines are all of equal length, width and blackness, while the spaces between each of the parallel lines are of the same width as the lines.

An image of the astigmatic test figure, created by a refracting system having equal refraction in every meridian, will show every line equally distinct.

If the refraction is unequal in various meridians, the focal length of the different meridians varies, and the screen cannot be placed in any position to receive the image of all the various series of lines. The screen being placed to receive a clear image of the lines in one meridian, those in the other meridians will appear more or less indistinct, because they are out of focus.

An image of the astigmatic test figure, created by any refracting system in which the refraction is unequal in various meridians, will show the series of lines of unequal blackaess and some less distinct than others.

Therefore, if any refracting system creates an image of an astigmatic test figure in which the lines do not all appear alike, it demonstrates that the system has not true spherical refraction, in other words, *that it is astigmatic.*

The astigmatic test figure makes an excellent object of which to create an image, and if such image shows some or all of the lines out of focus, lenses may be imposed until all the lines appear alike and distinct. Use the cigar box device in the experiments, or by placing a cylinder lens behind the spherical lens of the camera obscura, it may be made astigmatic. A couple of bent pins will serve to support the cylinder.

Suppose all the lines of the figure originally appeared blurred, if the addition of convex spherical lenses causes them to become less distinct, try concave sphericals. If all the lines can be brought out equally clear and distinct with either convex or concave sphericals, it will show that the refracting system possessed too much or too little refracting power consistent with the position of the screen.

If at the beginning it is seen that the lines in some one meridian are clear and the others blurred, a plane cylinder will be required to

correct the astigmatic error in the refracting system. It has been demonstrated that the two principal meridians are always at right angles to each other, therefore:—

If the lines in one meridian appear the most distinct, those in the meridian at right angles will appear the most blurred.

The axis of the correcting cylinder will be found to be parallel to the meridian in which the lines appear the most indistinct; an easy rule to remember will be to:

Always place the axis of the cylinder at right angles to the blackest lines, this applies if the cylinder be either convex or concave.

If all the lines appear indistinct, but some more so than others, use convex or concave sphericals as may be necessary until the lines in some one meridian are clear and distinct, then proceed as in the case where a plane cylinder was required.

Astigmatism is always created where the curvature is unequal in the various meridians, the refraction being unequal; it may occur also when the curvature is *equal* in all meridians by inclining the lens at such an angle to the incident rays that they undergo *unequal refraction.* This is due to the same phenomena that creates spherical aberration and is called *astigmatism by incidence.*

With a strong convex spherical lens, say ten dioptre, create an image upon a screen, the lens and screen both being in a vertical position. If the lens be tilted obliquely the image will immediately become blurred and less distinct the greater the inclination of the lens. It is caused by the astigmatic condition created by the lens in this position.

Persons wearing high power lenses experience annoyance through this phenomena if the lenses are not properly "set" before the eyes. Reading glasses should be tilted forward at the top to overcome this defect, the angle to be determined by experiment for each particular wearer.

The most perfect instrument of mechanical construction for the formation and recording of optical images is the modern photographic camera. It may be said to duplicate the functions of the human eye in everything except the ability to record color. It is capable of recording the intensity of light and may therefore be said to be possessed of the light sense. When equipped with a pair of matched lenses, for the making of stereoscopic photographs, it may be said to have the power of recording form and therefore has the form sense. It is within the range of possibility that the color sense may be added within a short time. The refracting system is corrected for chromatic aberration

and it is now possible to obtain a true achromatic lens, which is more than can be said for the human eye.

The iris diaphram, so called for its resemblance to the iris of the eye in its action, corrects the spherical aberration. The bellows permits of the focussing of the lens for all distances; in this respect it corresponds to the power of the eyes to accommodate for different distances. In the camera the distance between the refracting system and the screen is changed. In the eye the power of the refracting system is changed, the relative position of the screen and the refracting system being unchangeable.

In the steroscopic camera, two lenses having exactly the same refracting power are used to make two separate pictures of the same subject upon the same plate, side by side. The two lenses corresponding to the two eyes of a person, the line of vision for each being directed to the same object.

Stereoscopic pictures seem to be two pictures of the same subject exactly alike in every detail, but such is not the case. By reason of the distance between the lenses, corresponding to the average distance between the two eyes of a person, two different view-points are obtained and a slight difference in the pictures occurs. In each of the pictures will be found some objects that do not occur in the ether, some that are missing. This duplicates the function of binocular vision, that is, single vision with two eyes, the two images fusing or blending into one.

CHAPTER IV.

PHYSIOLOGY AND ANATOMY.

NO treatise upon the refraction of the eye would be considered comprehensive or complete that did not embrace the physiology and anatomy of the eye, so that the writer feels it is necessary to devote a chapter to the subject. No attempt will be made to write an authorative paper, nor will it be the aim to elucidate any new facts; too many text books have been written upon the subject, by far abler writers, to which the student is referred for fuller information than it is necessary to incorporate in this work.

The medical refractionist so frequently accuses the non-medical refractionist with lack of knowledge of the functions of the eye, and upon this lack of knowledge condemns his ability to correctly estimate and prescribe for refractive errors, that it behooves one to be as well informed as possible, to be able to talk to a patient as intelligently upon the subject as his competitor.

The sense of sight is not the result of a purely mechanical phenomena like the making of a photographic image with a camera, for it involves certain complex physical functions of each eye separately and working in unison. There must be a harmonious action of the two eyes so that perfect binocular vision may exist.

In order that the ocular refractionist may do justice to his patient, and credit to himself, he must understand the fundamental facts of the anatomy of the eyes and how they perform their functions.

This chapter is made up largely of matter taken from the writings of well known authorities, with such explanations as the writer is able to give in order to simplify the statements, which were originally intended for the use of medical students, an effort to give them in simpler language will be made.

It is a well known fact that in order to obtain as extended a field of view as possible it is necessary to seek an elevation, one climbs to the top of a hill in order to see as far as possible. Upon this principle Nature locates the eyes in the upper portion of the head, the skull being the most elevated portion of the human frame; thus, the advantage of position to secure a comprehensive view is obtained.

The next important fact noticed, is the protection afforded the eyes, by the bony cavities in which they are placed. These are called the sockets or *orbits* of the eyes and are in the form of an irregular cone or four sided pyramid, the apex being inward. The aperture of the orbit is larger than the diameter of the eye, being about one and three-eights of an inch in diameter, while the eye is about an inch in diameter. The space between the eye and the bony walls of the orbit is filled with cushions of fat that serve as further protection, and upon which the eye rotates freely. The principal opening into the orbit is at its apex, through which the nerve of sight, the *optic nerve* reaches the brain. The axes of the orbits are not, as would naturally be supposed, parallel, but converge toward the centre of the skull.

A further protection is afforded the eyes by the *eyelids*, which close together tightly and involuntary whenever any object is brought dangerously close to the eye. The edges of the eyelids are furnished with a thick row of short hairs that serve to ward off small particles of foreign bodies, such as dust, cinders, etc.

In connection with the eyelids may be considered the *lachrymal organs* that serve to keep the surface of the eye moist. If any small particles reach the surface of the eye, a copious flow of lachrymal fluid or *tears* washes away the offenders, as the eye is extremely sensitive to the presence of any foreign substance, a small cinder or any rough particle will set up a serious inflammation in a very short time.

The eye is spherical in form and about one inch in diameter, upon its outer surface is a section of a smaller sphere which increases its antero posterior diameter. This small sphere is attached to the larger in much the same manner as the crystal is attached to an open-faced watch. The axes of the eyes are parallel to each other.

The eye is composed of *three membranes* that enclose the *refracting media or humors* The membranes are the *Sclerotic*, the *Choroid* and the *Retina*. The humors are the *Aqueous*, the *Crystalline Lens* and the *Vitreous*.

The outer membrane is the sclerotic and is a tough fibrous membrane that gives form to the eye, it is what is commonly called the "white of the eye." The *Cornea* is a part of the sclerotic, forming about one fifth of its area, and is *transparent*. Looking at an eye obliquely the form of the cornea may easily be seen elevated above the larger sphere of the eye. The form of the cornea is similar to a convex lens. Where it joins the white portion of the sclerotic it forms a circular outline. The motor muscles are attached to the sclerotic. The cornea is made up of four layers, the outer of which is the *con-*

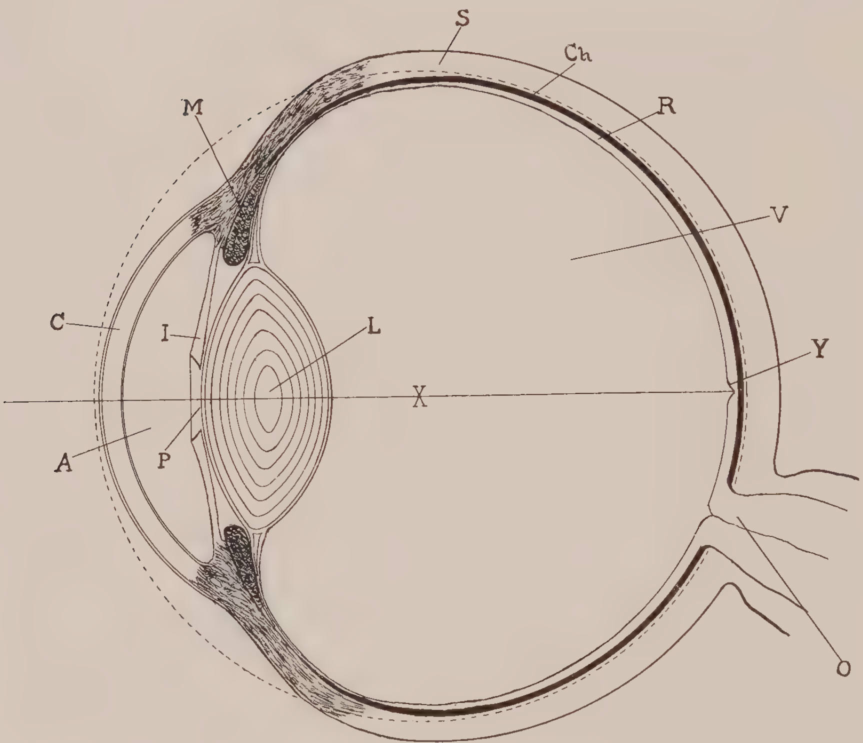

Figure 91.

A diagrammatic representation of a vertical cross section of the human eye.

S.—The sclerotic.
R.—The retina.
A.—The aqueous humor.
V.—The vitreous humor.
O.—The optic nerve.
I.—The iris.
X.—The centre of rotation of the eye.
Ch.—The choroid
C.—The cornea.
L.—The crystalline lens.
Y.—The yellow spot, or macula lutea.
P.—The pupil.
M.—The ciliary muscle.

The straight line through the centre of rotation to the yellow spot indicates the line of vision

The dotted circle shows the relative departure from spherical form of an approximately normal eye.

The crystalline lens is shown as having a nucleus and surrounding layers.

The measurements given in this cut are not intended to be exact, it is merely a diagram to show the principal parts of the eye.

junctiva. The portion of the conjunctiva covering the cornea is very thin and is free from vessels, it is the mucous membrane of the eye and covers the whole of the outer surface, also extending continuously and forming the inner coating of the eyelids.

The sclerotic is pierced at its inner or posterior portion by the optic nerve as it enters the globe of the eye.

The middle or second membrane is the choroid, it terminates forward in the *ciliary processes* and the *iris*. The iris is the curtain to regulate the amount of light entering the eye and assumes various colors in different individuals, it is that which makes a blue or a brown eye, etc. The iris is pierced by a circular opening called the *pupil*, it is merely a round hole in the curtain; it contracts and expands as the light increases or decreases in intensity, the expansion and contraction being a purely involuntary action.

The *ciliary* muscle, which is the termination of the ciliary processes, is behind the iris and surrounds the *crystalline lens;* by its action, contracting around the periphery of the lens, it permits the increase of the convexity of the crystalline lens and therefore its refracting power. This action constitutes the power of the eye to accommodate its refraction to focus light rays from objects at any distance.

The color of the choroid is a deep brown to black. It is pierced at the back of the eye by the optic nerve the same as the sclerotic. The choroid is made up largely of the blood vessels of the eye and the pigment that absorbs the light

The inner membrane is the *retina*. It is the expansion of the optic nerve after it enters the globe of the eye and is the nervous system that is sensitive to light. The retina decreases in thickness as it spreads toward the front of the globe and also decreases in sensitiveness to light.

The optic nerve shows with the ophthalmoscope as a round white disk, the point where the nerve enters the eye is not sensitive to light and forms the "*blind spot*" of the eye. Toward the outer side of the disk is the "*yellow spot*," or the *macula lutea*, which is a slight depression in the retina, at which the greatest sensitiveness exists, and upon which the line of vision falls when we look at an object; thus, we are compelled to change the direction of the look as we view different objects. The retina decreases in sensitiveness to light and sight impressions in every direction from the yellow spot in concentric circles.

The optic nerves originate in each half of the brain; they unite then separate, having crossed each other, and each passes through the

optic foramen, or aperture in the sphenoid bone, leading into the orbital cavity of its respective eye.

The *central artery* enters the eye with the optic nerve, and, with its branches, may be plainly seen with the ophthalmoscope as they spread out over the retina.

The *aqueous* or watery humor, fills the space between the crystalline lens and the cornea, and serves to distend the cornea and give to it its form. The *vitreous humor*, a jelly like substance, fills the space between the crystalline lens and the retina and distends the globe of the eye, forming its largest bulk.

The *crystalline humor* or lens is in form similar to a double convex lens, the outer surface is less convex than the inner surface. It is situated immediately behind the iris and is contained in a transparent, elastic membrane called the *capsule of the lens.* It is composed of concentric layers, the outer of which are soft and elastic but they increase in density and toughness toward the centre The lens measures about ten millimeters in diameter and about four millimeters in thickness. It is perfectly transparent and without color, this is also the condition of the other humors when the eye is in a normal healthy condition.

Tscherning gives an interesting description of the crystalline lens, among other facts he states that: "It must be noticed in the first place that this body is not homogeneous; its index gradually diminishes starting from the centre of the nucleus towards the periphery. The curvature of its layers diminishes also towards the periphery, so that each layer takes the form of a meniscus, the concavity of which is greater than the convexity."

Movement is imparted to the eyes, in order that the line of vision may be changed, by six muscles to each; by the action of these muscles opposing each other, the eyes are rotated about various axes of rotation and one centre of rotation.

The motor muscles of the eye are the Superior, Inferior, Internal, External and the Superior and Inferior Oblique muscles.

The four mentioned first are the principal ones, and as their names indicate, they are attached to the eye forward of its center respectively upon the upper, lower, inner and outer portion of the sclerotic. These four muscles are in the form of straight flat bands that spread out and attach themselves to the eye in a fan like formation at their termination. The *internal recti* turn the eyes inward, creating convergence of the visual lines. The internal is the largest of the muscles and is attached the farthest forward of all, reaching almost to the edge of the cornea.

The *external recti* are attached opposite the internal and rotate the eyes outward. The *superior recti* turn the eyes upward and the *inferior recti* downward.

The *superior oblique rectus* is not straight but passes over a kind of roll, which acts as a pulley, and is attached to the posterior of the globe, it rotates the eye inward and upward.

The *inferior oblique rectus* turns the eye inward and down.

It will be noted that only one muscle tends to turn the eye outward, all the others combine to rotate it inward.

In a concise description of the eye by Ludovic Hirschfeld, he says:—"The sclerotic is a tunic of protection, and the cornea a medium for the transmission of light. The choroid supports the vessels destined for the nutrition of the eye, and by its pigmentum nigrum absorbs all loose and scattered rays that might confuse t e image impressed upon the retina. The iris by means of its powers of expansion and contraction, regulates the quantity of light admitted through the pupil. If the iris be thin, and the rays of light pass through its substance, they are immediately absorbed by the uvea, and if that layer be insufficient, they are taken up by the black pigment of the ciliary processes.

"In Albinos, where there is an absence of pigmentum nigrum, the rays of light traverse the iris, and even the sclerotic, and so overwhelm the eye with light, that sight is destroyed, except in the dimness of evening, or at night.

"In the manufacture of optical instruments, care is taken to color their interior black, with the same object, the absorption of scattered rays. The transparent lamellated cornea, and the humors of the eye have for their office the refraction of the rays in such proportion as to direct the image in the most favorable manner upon the retina."

For a description of the nerves of motion and feeling of the eye the student may consult any standard work on anatomy of the human body.

CHAPTER V.

PHYSIOLOGICAL OPTICS.

AS the title of this chapter indicates, it treats of the formation of images by the human eye. The method, by which this is accomplished, is based upon the principles of refraction with which the student is now familiar. The eye, as an optical instrument, is frequently compared to a camera, and, no better comparison could possibly be made. To make good photographs the refracting system must be perfect and the screen, or plate, must be "in focus." In order that perfect vision may be had, the refracting system of the eye must be free from errors and the retina must be situated at the focal point of the system.

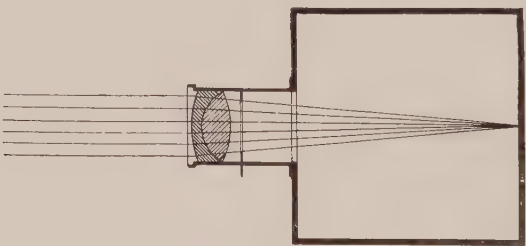

Figure 92.

Sectional view of a camera, the parallel lines represent light rays entering the lens and brought to a focus on the plate.

In figure 92 is shown a sectional view of a camera, the lens tube, projecting from the body of the camera, carries the refracting system. The parallel lines represent light rays from an object more than twenty feet distant, they enter the lens aperture and undergo refraction by the achromatic lens; just behind the lens is situated the diaphragm, which cuts out the marginal rays and corrects the spherical aberration. Beyond the diaphragm, the rays are seen converging to a point upon the sensitive plate at the back of the camera. The bellows arrangement for focussing the camera, by changing the position of the plate with regard to the lens, is not shown in the diagram, every-

one knows how a camera is made and it was not thought necessary to show this.

The parallel rays shown in the figure are supposed to come from a *single point* upon the object, their focus thus represents but a *single point in the image.* The image of the object is made up of innumerable focal points, in fact, in order to be a perfect image, it must consist of the focus of rays of light from every point of the object.

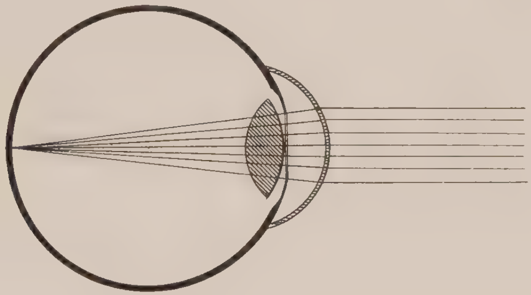

Figure 93.

Sectional view of the eye showing the similarity to the action of a camera; parallel rays o light being brought to a focus upon the retina.

Figure 93 is a sectional view of the eye, for comparison with the camera under similiar conditions, as shown in figure 92.

The parallel rays enter the aperture of the eye which is the corneal surface, undergo refraction by the cornea, a portion are diaphragmed out by the iris, the remainder undergo more refraction by the crystalline lens and focus upon the retina without any effort of the accommodation.

The ideal conditions of vision are only obtained with a normal or *emmetropic* eye, the conditions that exist in such an eye will first be explained. Figure 93 represents an emmetropic eye.

The refracting system of the eye is made up of the cornea, crystalline lens and the humors, its aberrations are partially corrected by the iris, acting as a diaphragm and the difference in the index of refraction and the power of dispersion of the various parts.

The index of refraction of the cornea is 1.37; of the crystalline lens 1.42; of the aqueous and vitreous humors 1.33; comparison being made with air as a standard, the index of refraction of air being taken

as 1.00. The eye is not achromatic, but the pupil, by contracting, reduces the chromatic aberration as well as the spherical aberration.

The refracting system of the emmetropic eye is about (58. D.) fifty eight dioptres in power, this means that the focal length of the eye is about (.7) seven-tenths of an inch. Of the dioptric power of the eye, the cornea contributes about (42.5 D.) forty two and a half dioptres, the crystalline lens about (15.5 D.) fifteen and a half dioptres. To comprehend what this means, and realize how powerful and sensitive an instrument of refraction the eye is, if one will consider that in the test case the most powerful convex spherical lens is a 20. D., and if the eye had a dioptric power of this amount, it would have to be two inches in diameter, some idea will be obtained. If the eye were only an inch in diameter it would require 40. D. of refraction; but as it possesses nearly 60. D. it is only a little more than three quarters of an inch in its antero-posterior diameter.

The refracting system of an emmetropic eye is in effect a convex spherical lens; having equal refraction in every meridian, the curvature of the cornea must be the same in every meridian. This is also true of the surfaces of the crystalline lens.

When designating the dioptric power of a lens as a 4.00 D. it is understood to mean that it possesses the power to bring *parallel* rays of light to a focus at a distance of 10 inches, or that its principal focus is four dioptres.

When the statement is made that an emmetropic eye has 58. D. of refraction, it means that *parallel* rays of light entering such an eye are brought to a focus exactly upon the retina, which is situated at e actly the focal point of the system.

The image created upon the retina is *real and inverted;* that we do not see things up-side-down is difficult to explain, just as it is impossible to tell exactly where the seat of sight is located in the brain, and *how we see.* It is evidently a matter of education, one of the things we learn intuitively without knowing or realizing how we learn it.

It has never been determined accurately what is the standard of a normal eye, that is, just how much dioptric power it should possess. The reason for this is obvious There is no doubt that there exists a difference in the axial length of the eyes, yet if the dioptric power of each is such that the retina is situated at exactly the principal focus of the system, normal sight conditions will obtain. Thus different eyes may be emmetropic, yet they may have different powers of refraction. It is quite possible to select a number of men and class each as perfect specimens of manhood; though there may exist a wide

comparative difference between them, yet so long as each possesses the required proportions, each may be perfect.

A definition of a normal eye may be given as:—

An emmetropic eye is one possessing equal refraction in every meridian, the retina is situated exactly at the principal focus of its refracting system under static conditions. (*By static conditions a state of rest is meant.*)

It will be remembered that light rays coming from a distance of twenty or more feet are in effect parallel. If any object situated at this distance be viewed, the rays from it enter the emmetropic eye and passing through the refracting system are brought to a focus upon the retina, without any effort, forming a real image thereon. This optical condition, due to light impulse, creates a nerve impulse in the retina, which is transmitted through the optic nerve to the centers of vision in the brain; there, some mysterious action takes place and sight is the result.

Suppose the object seen be approached, so that it is much nearer to the eye than twenty feet, the light rays will no longer be parallel when they enter the eye but will be divergent, the degree of divergence increasing the nearer the object is approached. Now, if as parallel rays they focussed upon the retina, as divergent rays they will not, but would come to a focus at a point back of the retina. In order to overcome this condition the antero-posterior diameter of the eye would have to lengthen, thus carrying the retina farther away from the refracting system, or the refraction of the eye would have to be increased to enable it to adapt itself to the divergent rays.

The latter is what actually takes place, the refracting system changes its power, accommodating it to focus either parallel or divergent rays upon the retina. This is called the *accommodation of the eye.*

Accommodation is accomplished by an increase in the convexity of the anterior surface of the crystalline lens, the ciliary muscle by contracting permits the lens to bulge forward of its own inherent elasticity.

Let figure 94 represent a sectional view of the crystalline lens. The anterior surface has a longer radius than the posterior, and therefore has less refracting power, in fact, in a state of rest, the anterior surface has only about two-thirds of the refracting power of the posterior. The refracting power of the anterior surface is about + 6. D., of the posterior surface about + 9.50 D., when the crystalline lens possesses its minimum refracting power.

When the accommodation is exerted the curvature of the anterior surface increases, that is, it deepens, and its radius becomes much

smaller. This increases the refracting power of this surface and therefore adds to the refracting power of the lens.

The dotted line indicates the curvature of the anterior surface under accommodation. The position of the iris and pupil are shown during accommodation.

This diagram is purposely made large and the curvatures shown are exaggerated, so that it may readily be seen what takes place to effect accommodation, or change of focus in the eye. A, indicates the anterior surface; P, indicates the pupil.

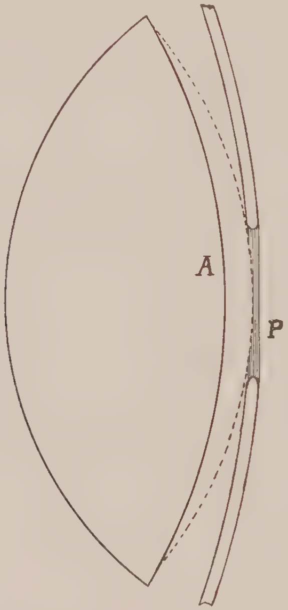

Figure 94

Sectional view of the crystalline lens in a static condition, also with the accommodation exerted. The dotted line indicates the change in the curvature of the anterior surface during accommodation. The position of the iris and contraction of the pupil is also indicated during accommodation. A, indicates the anterior surface; P, the pupil.

When an eye is in a static condition, or state of rest, it possesses its least refraction and is therefore focussed for the greatest distance

possible for it. Under these conditions it is said to be focussed for its *far point, or punctum remotum.*

When the accommodation is exerted to its fullest power, the eye possesses its greatest refraction. It is then focussed for its *near point, or punctum proximum.*

Objects situated at the near point of an eye may be seen distinctly because the eye will focus the divergent rays and create a clear image, if the object be brought closer than the near point, a clear image cannot be formed, and distinct vision cannot be had.

The distance between the near and the far point is called the *range of accommodation* of the eye.

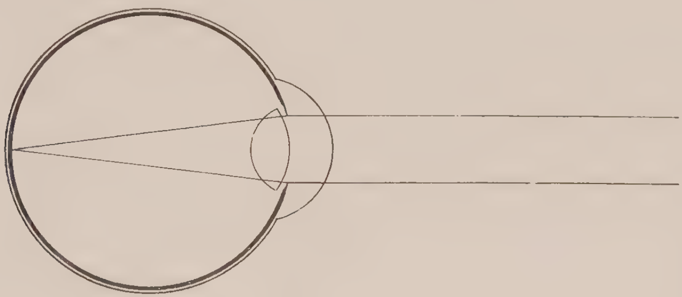

Figure 95.

Diagram to represent an emmetropic eye adapted for distant vision. Parallel rays of light are brought to a focus upon the retina. The pupil is expanded, or rather, not contracted.

The amount to which an eye is capable of increasing its refraction is called its *amplitude of accommodation*, it is measured in dioptres.

The amplitude of accommodation decreases with age, at about the age of ten years it begins to be manifest. With the decrease in the amplitude, the range of accommodation necessarily becomes less and less, and in order to see clearly, a person must hold print farther and farther away. When a person is unable to read average newspaper and book print at ten inches, because of the decrease in the amplitude of accommodation, *presbyopia* is said to have commenced. Presbyopia will be explained later.

It is obvious that the amount of accommodation required will depend upon the distance the object it is desired to see is situated from the eye. From a distance of forty inches, the divergent rays would be rendered parallel by a one dioptre convex sphere, therefore, the eye would have to accommodate one dioptre. If the object be ten

inches away, four dioptres will have to be supplied by the accommodation. It will thus be noted that all of the accommodation is not necessarily used at all times. All the accommodation is required to see an object situated at the near point of the eye.

Accommodation is an involuntary action, the same as the contraction and expansion of the pupil is involuntary, and for this reason few people are conscious of the act.

Let figure 95 represent an emmetropic eye adapted for distant vision. The pupil is shown expanded and parallel rays entering are brought to a focus upon the retina.

Figure 96 represents this same eye adapted to bring to a focus upon the retina the rays from the object at P which is ten inches away. The accommodation exerted is four dioptres. The lens is shown having a deeper curvature upon its anterior surface. The pu-

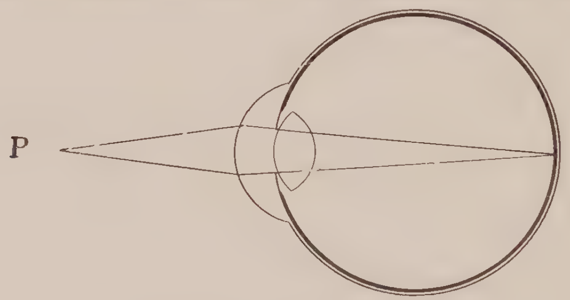

Figure 96.

Diagram to represent an emmetropic eye adapted for vision at close point. Divergent rays of light are brought to a focus upon the retina. The pupil is contracted.

pil is also contracted, an action that occurs with accommodation.

A simple experiment to detect the act of accommodation in one's own eye may be made by anyone. Stand before a window having a lace curtain before it, let the eyes be eight or ten inches from the curtain. Look across the street and the mesh of the lace will disappear. Without any movement of the head now look at the threads of the curtain; when they appear distinctly, the object across the street will have become so blurred as to be indistinguishable.

Why is it that the distant object disappeared when looking at the curtain, and the mesh of the curtain disappeared when looking at a distance? The rays of light from both objects enter the eyes all the time.

Let figure 97 represent the emmetropic eye adjusted for distance, the parallel rays focus upon the retina. The divergent rays from the point P, represented by the dotted lines, do not focus upon the retina

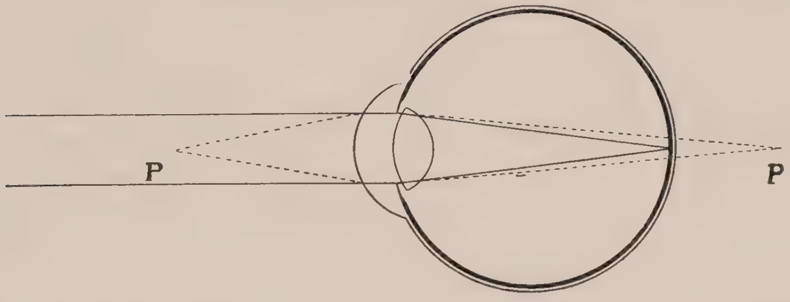

Figure 97.

An emmetropic eye adapted for distance, the divergent rays represented by dotted lines, form circles of diffusion upon the retina, their focus being behind the retina.

but at the point P′ back of it. The rays from the object at P form circles of diffusion upon the retina and the object does not appear distinctly.

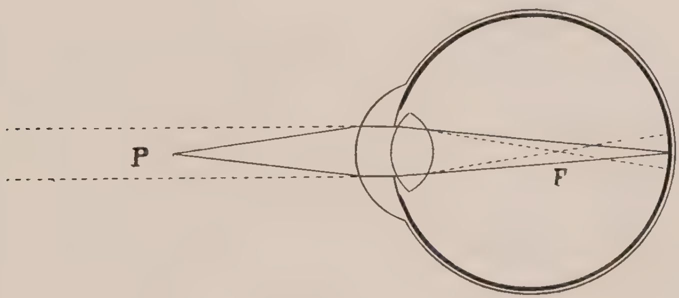

Figure 98.

An emmetropic eye adapted for a near point. The parallel rays, represented by dotted lines form circles of diffusion upon the retina, their focus being in front of the retina.

Figure 98 represents the eye adjusted for the object P. Parallel rays from distant objects enter the eye at the same time but are brought to a focus at F, a point in front of the retina. The dotted lines represent rays from the distant object, they meet and cross at

the point F, then diverge and reach the retina to form circles of iffusion, and therefore no distinct image.

It is thus demonstrated, that the eye sees clearly, only those objects lying in the plane for which it is at the instant adjusted.

In looking about a room of average size, in looking at objects within one's reach, in reading, etc., it is seen that the accommodation must be constantly in action. The more we know of this wonderful function of the eye, the more marvelous we find it to be. Our visual comfort is largely dependent upon the action of the accommodation. If excessive demands are made upon it for any cause, we suffer for it in visual discomfort.

There seems to be so much uncertainty in the minds of many about the theory,and the mechanism of the accommodation, and it has such an important bearing upon the work of the refractionist, that the student is urged to study the subject carefully. The limits of this work preclude the possibility of covering the subject fully, nor is it necessary, in view of the excellent works in existence. Tscherning's Physiologic Optics is recommended, the chapter on accommodation is particularly valuable.

A few extracts will be quoted from it. "To explain the mechanism of accommodation *Helmholtz* announced the following hypothesis, which he gave, however, only as probable: In a state of repose the crystalline lens is kept flattened by a traction exerted by the zonula. When the ciliary muscle, of which he considered the anterior extremity as fixed, contracts, it draws the choroid slightly forward, which relaxes the zonula. Having become free, the crystalline lens then swells by its own elasticity, approaching the spherical torm."

"This hypothesis does not seem to have been at first generally accepted. *Hencke* and other authors, tried to explain the phenomena observed, by other hypotheses. After having discovered the supposed circular fibres of the ciliary muscle, *H. Muller* thought that this muscle changed the form of the crystalline lens by a direct pressure, an idea which was abandoned when it became known that the ciliary body never touches the crystalline lens.'

"The contents of the crystalline lens are composed, in the adult of two parts, the nucleus, which cannot change its form, and the superficial layer, which, on the contrary, possesses this faculty to a very high degree; its consistence is very nearly that of a solution of very thick gum. I call this layer the *accommodative layer* in order to show that it is due to it that the eye can accommodate itself. Accordingly as age advances, the nucleus increases while the accommodative layer

diminishes, and with it the amplitude of accommodation. The whole is surrounded by a capsule which is inextensible or very nearly so."

"It has always been supposed that a traction exerted on the zonula must flatten the crystalline surfaces, while a pressure exerted on the borders would have, on the contrary, the effect of increasing their curvature. Nothing of the kind: a pressure exerted on the borders has, on the contrary, the effect of flattening the surfaces, while a traction exerted on the zonula increases the curvature of the surfaces at the middle, while flattening them toward the periphery."

"To verify this fact we take the crystalline lens from the eye of an ox or a horse, which must not be too old, with the capsule and

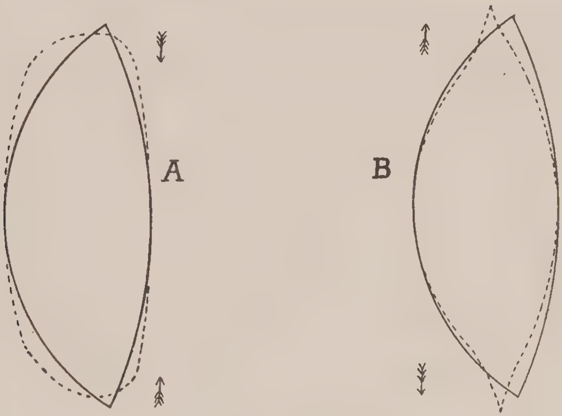

Figure 99.

Change of form the crystalline lens assumes; A, when pressure is exerted upon the periphery; B, when a pull is exerted upon the zonula. (This cut reproduced from Tscherning's Physiologic Optics.)

zonula of *Zinn*. It is easy to see that by compressing the borders the surfaces are flattened; to observe the effect of traction we take hold of the zonula on both sides, very near the crystalline lens, and, by pulling, we can, on looking at the crystalline lens sideways, see that the anterior surface assumes a hyperbolic form."

See figure 99. The dotted line indicates the form which the crystalline lens assumes: A, by a lateral pressure; B, by a traction exerted upon the zonula. The arrows indicate the direction of the forces.

The conditions governing refraction in the normal eye being understood, we will turn once more to the analogy of the camera to explain another condition required to obtain vision.

In making a photographic picture of some object, the camera is directed toward the object, so that its image occupies a prominent position on the plate. The plate being then focussed for the object, some of the other objects in the picture will no doubt be out of focus.

In order that the eye may register the image, it is not merely necessary that the image be focussed upon the retina by the refracting system, but it must fall upon a certain portion of the retina.

There is a point in the retina that is more sensitive than any other to light impressions, it is called the *macula lutea*, and in order that the clearest perception of an object may be had, its image must fall upon the macula.

In order that this may occur, the eye is said to "*fix*" the object it is desired to see. A straight line drawn from the object fixed, through the optical centre of the refracting system to the macula, is the *line of vision*. This explains the shifting movements of the eyes in their orbits, the line of vision being changed from point to point of fixation. As the image falls upon a portion of the retina removed from the region of the macula it is indistinct; the farther away from the macula, the less distinctly the eyes can discern objects, until the limit of visual impressions of the retina is reached.

When fixing an object, the eye also perceives other objects surrounding it, less distinctly the farther they are removed to the right or left, above or below it.

The amount of space the eye perceives at one time, when fixed upon an object, is called the *field of vision*.

The macula lutea is the centre of vision in the visual field, which is in the form of an irregular oval, but the macula is not in the centre of the field.

The line of vision corresponds nearly to the principal axis of the eye.

In the last paragraph of Chapter III. reference is made to *binocular vision* ; it means, *single vision with two eyes*. Each eyes receives its own image and records it, the two are transmitted to the brain and there fused into one.

So far, only single vision has been considered, but in the work of ocular refraction, this condition—binocular vision—must be taken into account, for it involves the most complications that occur in the correction of errors of refraction.

Let us see how binocular vision is brought about.

Take, for example, a person having a pair of eyes that are emmetropic. Suppose him to observe an object, looking at it with both eyes. If one be covered, he will see the object with the other, showing that single vision exists. Now repeat the experiment, covering the other eye ; again, single vision obtains. This proves that vision is recorded with each eye.

With both eyes directed toward the object, only *single vision occurs*, showing that in some mysterious manner, or rather by some mental process, the two retinal images are blended or fused into one.

It has just been demonstrated, that the eye must "fix" an object to see it clearly. When binocular vision is had, each eye separately must "fix" it. This requires, as we have seen, a muscular action; the recti being called into play.

This involves intimate relations of the lines of vision of the two associated eyes, *so that like portions of each image falls upon identical points in the retina of each eye.*

When normal conditions of the motor muscles of the eyes exist, binocular vision is made possible by a co-ordination of the lines of vision. This is called *Orthophoria*, any deviation from it is called *Heterophoria.*

Binocular vision exists as a result of the combined action of Refraction, Accommodation and Co-ordination of the lines of vision.

An emmetropic eye, observing an object at a distance of twenty or more feet, exercises no accommodation, because the rays of light that reach the eye from the object are parallel.

When two emmetropic eyes are associated, in looking at a distant object, they do not accommodate, and it is also considered that their visual lines are parallel.

If an object nearer than twenty feet is observed, the visual lines are no longer considered to be parallel, but they converge to meet at the point observed.

This is called the *Convergence* of the eye.

It is known that under these conditions accommodation is also required, to focus the light rays from the object upon the retina.

Accommodation and Convergence are intimately related. Nature intended that they should be so associated, that they should work together in harmony. When we accommodate, we should also converge ; when we converge, we should also accommodate.

A given amount of accommodation should be accompanied by a definite degree of convergence.

The degree of convergence is measured by what is termed a meter-angle; it corresponds to the unit of refraction, the dioptre. The meter-angle is not a fixed quantity like the dioptre, because it varies in different persons according to the inter-pupillary distance.

Any departure from normal conditions of refraction disturbs the harmonious action of accommodation and convergence. Such disturbance is frequently the cause of ocular distress.

The optical functions of the human eye have so far been explained, and comparisons have been drawn between it and an optical instrument. In so doing, only normal conditions of refraction in the eye have been discussed, to show how the eye is capable of creating images, and their reception upon the retina.

The study of the subject has thus involved phenomena, which can be explained according to well known physical laws. The next step is the consideration of phenomena of vision, that involve physiologic and psychologic conditions.

By physiological conditions, is meant the recognition of form by the retina, and the transmission of the same by the optic nerves to the brain centres of vision. By psychologic phenomena, we mean the translation of these nerve impulses by the brain into what we term sight. Only the first conditions come within the scope of this work. The study of the latter is commended to the advanced student of optics as being interesting, but unnecessary, in his work.

The image being formed upon the retina, which is sensitive to light, certain nerve impulses are created and transmitted by the optic nerves to the centers of perception in the brain. These give rise to the senses of recognition of light, color and form. The first two may be dismissed with a few words, as they are not embraced within the limits of this work.

The light sense is the ability to recognize difference in the intensity of light.

The color sense is the ability to distinguish between different colors. Lack of this sense, or a portion of it, is called *color blindness.*

The most important of all is the form sense, that is, the ability to recognize form.

The measure of the ability to recognize form, is called the visual acuity of the eye.

For determination and record of the visual acuity, some method had to be followed; some standard by which to measure, adopted.

A single point will make a single retinal impression; two points, *not too close together*, will be recognized separately; if they are too close to each other, they may appear to the eye as but one.

If a straight line be drawn from each of two separately recognized points, through the optical centre of the refracting system (the nodal point), to the retina, they will meet and cross each other at the nodal point forming an angle.

The smallest angle under which two points may be recognized, is the *measure of the visual acuity*. In the average normal eye this angle has been determined to be one minute, or one sixtieth of a degree. A definition of visual acuity may be given as:—

Visual acuity is the ability to recognize form. It depends upon the anatomical formation of the retina and its sensibility to recognize light impulses, the ability of the optic nerve to transmit these impulses, and ***the centres of vision*** *to interpret them.*

Parallel lines of equal width, separated by spaces the same width as the lines, the width of each line subtending an angle of one minute, are used as tests of visual acuity. Upon this principle the standard test letters of Snellen are constructed, the width of each line of the letters is such that two opposite points on the line, subtend an angle of one minute with the nodal point of the eye.

To measure the visual acuity, it is usual to measure the angle of vision for distance; the test type being placed at least twenty feet away, so that the accommodation may not be called into play.

In the formation of Snellen's test letters, a square that subtends a five minute angle is used and this is subdivided into squares of one minute angle each, making twenty five in all. See figure 100. The letters are formed upon the principle given above, of three parallel lines of equal width separated by two spaces of the same width. In this manner each letter occupies a square of five minute angle. At a distance of twenty feet, a five minute angle will include a square of about three-eighths ($\frac{3}{8}$) of an inch, the normal test letter for twenty feet will thus measure about three-eighths of an inch high and the same width. At forty feet the same five minute angle will include a square of three-quarters of an inch.

In figure 100 the standard sizes of test letters given are for twenty, thirty, forty and fifty feet as indicated by the number placed above each letter.

The standard of normal acuity of vision that has been established is not absolute. In some eyes the rods and cones are placed more closely together, and a hyper-acute vision may obtain. It will not be

uncommon to find, in testing eyes for visual acuity, that some can recognize letters that are much smaller than those that are selected as the standard.

In order to make the measurement of the visual angle plain, let figure 101 represent an emmetropic eye; P, its nodal point. At a distance of two hundred feet is located a letter E, it occupies a square of about three and three-quarters inches.

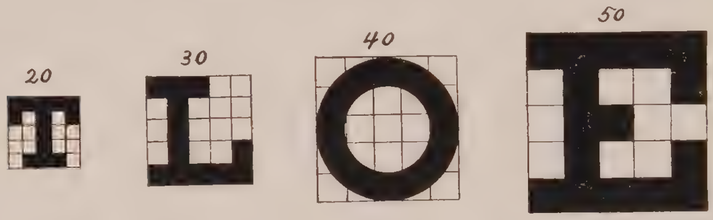

Figure 100.

Principle upon which standard test types are constructed, each small square represents ae angle of one minute, the whole letter is contained in a square that subtends an angle of fiv minutes. The letter T represents the standard size for twenty feet; the L, for thirty feet the O, for forty feet and the E for fifty feet.

From two opposite points, A and B, on the letter, draw the straight lines A P and B P, through the nodal point P. Extend these lines to meet the retina at A′ and B′. At a distance of 100 feet the letter T is placed, its size being such that it is just included between the lines A P and B P. At sixty feet the letter L is seen under the same conditions, while at forty, thirty and twenty feet respectively, are placed the letters O, F and C.

From the figure, it will be seen that all of these letters form upon the retina the same size image because they are included within the same angle. The size of the retinal images of all these letters at the distances given is the same, and is measured by the distance between the points A′ and B′.

This demonstrates that if an eye can recognize a letter of the size of C at twenty feet, it will be able to recognize a letter of the size of E at two hundred feet, because each forms the same size retinal image.

In recording the visual acuity, if an eye can recognize the standard letter for twenty feet at a distance of twenty feet, its visual acuity is recorded as 20/20. If at twenty feet an eye can only recognize the standard letter for fifty feet, its visual acuity is recorded as 20/50. The numerator of the fraction showing the distance at which

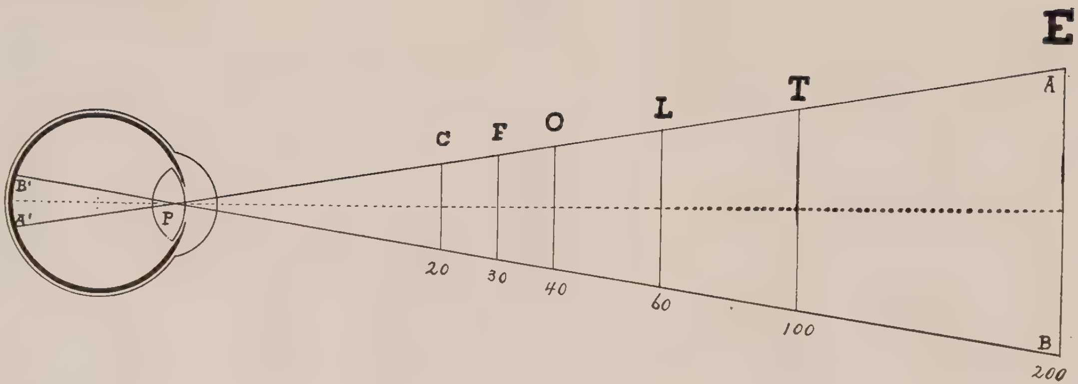

Figure 101.

Diagram to illustrate the visual angle. P. indicates the nodal point; A.P.B. the visual angle; A′B′ opposite points on the retinal image. The graduated letters, C, F, O, L, T and E. represent the standard size test types for the distances indicated respectively as 20 30, 40, 60, 100 and 200 feet. They all subtend the same angle and each forms a retinal image of the same size. This diagram does not follow proportions, if it did the lines would be so close together that it would be impossible to convey the ideas it is intended to explain.

the test was made from the card, the denominator of the fraction indicates the size of standard test letters recognized by the eye under examination.

The illumination of the test card is an important factor in determining the visual acuity. The card should be seen in daylight of average brightness, or under artificial illumination equally as good. No matter how sharp ones vision may be, they cannot see in the dark. The card should have an even amount of illumination throughout its entire surface.

Some refractionists have their test cards brightly illuminated, while the patient is placed at the required distance and in comparative darkness. Tests for visual acuity under these conditions are not dependable, the lighting of the testing room, when the visual acuity is ascertained, should be uniformly good in order to obtain reliable data.

EMMETROPIA.

The human eye is a most wonderfully delicate and beautiful optical instrument, and if all eyes were perfect, meeting all the conditions that have been explained as necessary for normal vision, the study of its construction (structure) and the operation of its functions, would well repay any student

If all eyes were emmetropic, there would be no need for the optician's product; glasses (lenses) would simply be required to help the Presbyope, and would merely consist of simple convex sphericals, up to three dioptres in power.

So far, in the study of Ocular Refraction, the conditions required for *normal vision only* have been explained. This is logical, for when one knows, and is able to recognize normal conditions, any departure from the normal is easily detected.

It would be supposed that abnormal sight conditions would be few, compared to the many normal eyes, but facts that are indisputable, prove the contrary.

The abnormal sight conditions that may be corrected with glasses (lenses), are classed as *errors of refraction*, and are embraced under the one general term *Ametropia.*

The proportion of Emmetropic to Ametropic eyes is extremely small.

Prof. Helmholtz said:—" If an optician were to bring to me an optical instrument as full of errors as the average human eye, I should return it to him as absolutely useless." This is perhaps a severe criti-

cism. Dr. Francis Valk said:—"I believe that there are very few persons who have perfectly normal vision even from their birth, although perhaps many of them have no trouble with their eyes, and have always supposed their sight was equal to that of the perfect standard." This fact was well demonstrated a few years ago by Prof. D. B. St. John Roosa, in an examination of a number of gentlemen, all students, whose age ranged from twenty-one to thirty-two years, who had never been conscious of any visual weakness. The results of this examination were, that only one fifth had normal eyes.

A more conservative statement than that of Prof Helmholtz, is that of M. Mascart, who said:—"The eye has all possible defects, but only to such an extent that they are not harmful."

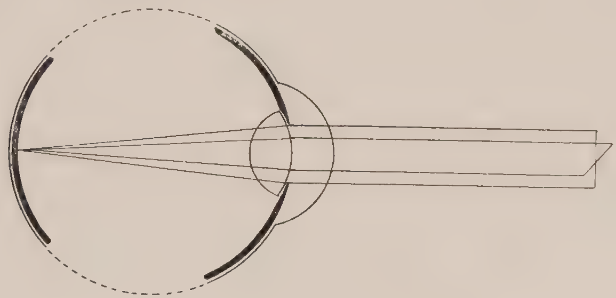

Figure 102.

Diagram to represent a sectional view of an Emmetropic eye. Parallel rays of light, lying in two planes at right angles to each other, are represented passing through the refracting system in its vertical and horizontal meridians, and brought to a focus upon the retina.

Let figure 102, represent a sectional view of an emmetropic eye. The parallel lines, represent light rays, lying in two planes at right angles to each other, entering the eye and brought to a focus on the retina.

The student may not grasp the meaning of the expression,—*two planes at right angles to each other*,—which is so frequently used in speaking of the refraction of the eye, being equal or unequal, in two meridians, at right angles to each other. To make its meaning clear, cut two pieces of card-board the size and shape of I and II, illustrated in figure 103, that is, an inch wide and four inches long; for a distance of two inches the sides are parallel, for the other two inches, tapering to a point.

Cut another piece of card-board two inches square, see III, figure 103, and draw upon it a circle P, an inch in diameter. Draw the diameters A. B. and C. D. at right angles to each other.

With a sharp knife, cut through the dotted lines indicated on I, as X. Y.; on II, as F. X.; and III, as A. B. and C. D. Slip I and II together, and push the four bladed point thus made, through the cuts A. B. and C. D. in the circle P, as shown in IIII, figure 103

As thus placed, and shown by IIII, figure 103, the square card III represents that portion of the globe of the eye surrounding the cornea, the circle P, represents the pupil. The two cards I and II, represent two bands of light composed of parallel rays, *lying in two planes at right angles to each other*, they pass through the pupil in the meridians at 90° and at 180°, and meet at the focus, or point F, which is supposed to be at the retina.

Through the aid of the simple device just described, and illustrated by figure 103,—which every student is urged to make for himself,—the condition of vision which figure 102 is intended to represent, will be readily understood. The same idea will be used to demonstrate the other conditions of refraction that occur in the eye.

In figure 102, the parallel rays traversing the two planes at right angles to each other, are shown entering the emmetropic eye in the vertical and horizontal meridians. As the eye possesses equal refrac-

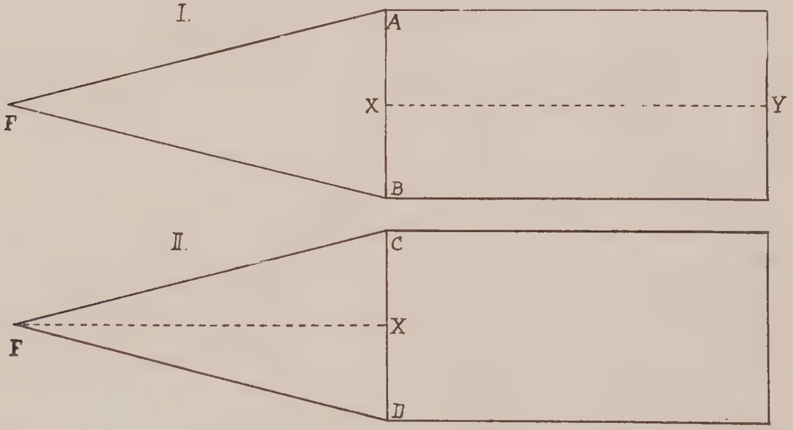

Figure 103 (*Continued on next page*).

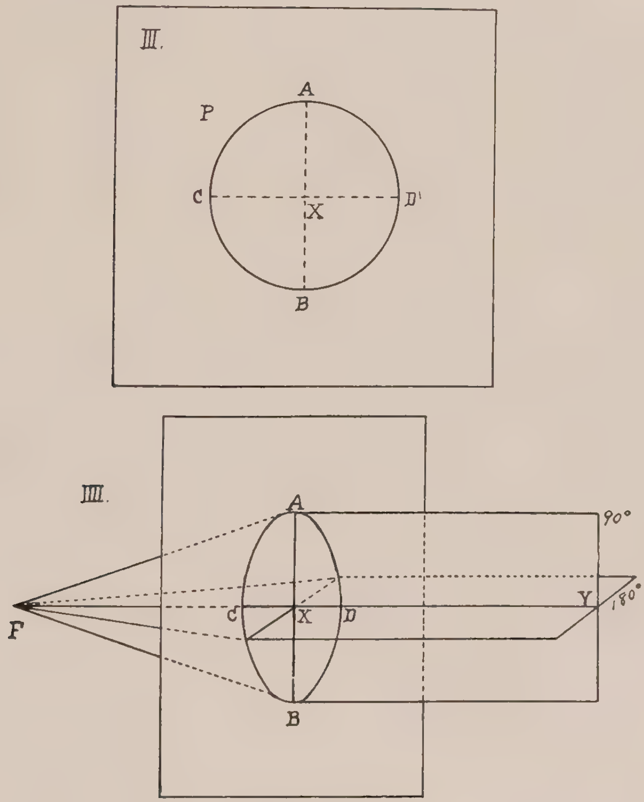

Figure 103. (*Continued*).

Diagram to explain construction of card-board model, to represent a section of the eye surrounding the cornea; the pupil; and rays of light traversing two planes at right angles to each other, and entering the eye. From card-board of fair weight, cut the two forms shown as I and II, mark the dotted line X Y on one, the dotted line F X on the other. Cut out another form like III, laying off the circle P, and dotted lines A B and C D. With a sharp knife cut through the dotted lines. Put the model together in the form shown by IIII.

tion in every meridian, these rays are shown to converge, and focus upon the retina. The eye is supposed to be in a static condition, that is, the accommodation is at rest, and the eye is focussed for its far

point. The dotted circle is supposed to pass through the optical centre of the refracting system and its principal focus; the retina is seen to be located at its principal focus.

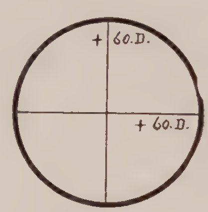

Figure 104.

Vertical and horizontal meridians of an emmetropic eye, represented as possessing + 60. D. of refraction.

In the beginning of the chapter, the statement is made, that the average emmetropic eye possesses about + 58.D. of refracting power. For demonstration purposes, the author will arbitrarily assume that an eye that is emmetropic will possess + 60. D. of refraction.

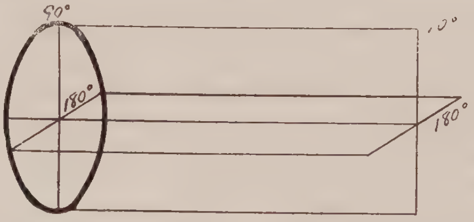

Figure 105.

Diagram to represent vertical and horizontal meridians of an eye, and rays of light traversing two planes at right angles to each other entering the pupil.

Let figure 104, represent the pupil of the emmetropic eye, illustrated by figure 102. In the vertical and horizontal meridians, which are represented, it will be found to measure + 60. D. as shown in the figure.

Being the equivalent of a spherical lens, the power of the refracting system will be the same in every meridian; for convenience and simplicity, the vertical and the horizontal meridians are selected for demonstration. It is easy to remember that they are at right angles to each other.

Any other two meridians at right angles, would serve the same purpose, say;—75° and 165°, or 10° and 100°,—but one has to pause and calculate their relative positions.

Figure 105 may serve to simplify the meaning of figures 104, 108, 111 and 114. The circle P represents the pupil, the vertical and horizontal meridians are designated as 90° and 180°, and the light rays traversing these meridians are also indicated by the planes 90° and 180°.

AMETROPIA.

An ametropic eye may possess equal refraction in every meridian, but the retina is not situated at the principal focus of its refracting system under static conditions. Or, the refraction may not be equal in every meridian.

This definition is just the opposite of that for emmetropia, and is purposely put in this form to make it easy to remember.

In writing of the errors of refraction under the title of this chapter,—" Physiological Optics,"—the author does not propose to go into the details of their correction beyond an explanation of the character of the lenses required, and how they affect the vision, by changing the direction of the rays of light before they enter the eye.

The reason for this is, that the author does not believe that the student should depend solely upon the writings or teachings of any one person. It gives the student a more liberal education to learn from a number, besides, no one person knows it all, nor is capable of imparting his knowledge of every phase of a subject equally well, so that it is wisdom to learn the views and opinions of as many as possible, upon a topic of a scientific nature.

The errors of refraction and their correction, is the subject-matter of numerous good text books, the student is referred to them to study in connection with this work. A few will be suggested, the author, personally, having found them valuable. " Errors of Refraction " by Valk. " Physiologic Optics " by Tscherning. " Refraction " by Hartridge. " Refraction and How to Refract " by Thorington.

In the introduction to this series of papers, written nearly a year ago, this statement was made:

" It is the author's conviction, that the greatest success at present is being made, and in the future will be attained, by that class of operators, who make Retinoscopy the corner-stone of the adapting of lenses to the correction of refractive errors. The aim of the work

will, therefore, be to teach the fundamental principles of Retinoscopy."

Since this was written the writer has undergone no "change of heart," but is a more enthusiastic advocate of Retinoscopy than ever. The subjects that have been covered so far are necessary to the study in question, and the remainder of this chapter is needed to round out the knowledge of the student, preparatory to taking up the study of Retinoscopy. This explanation is given, so that the student may understand the writer's motive. It will also serve to explain why the errors of refraction of the eye, and their corrections, are treated so briefly in this chapter.

In extenuation, it may be said, that the most lengthy paper upon a topic does not necessarily contain the most information. The author has endeavored to make the chapter on Physiological Optics comprehensive yet condensed.

Ametropia may be sub divided, and considered under three heads, viz:—*Hypermetropia*, *Myopia and Astigmatism.* By some writers, *Presbyopia* is also considered as a condition of Ametropia. This is hardly correct, as Presbyopia is not an error of refraction, it is due to a physiological change that takes place in all eyes alike. At a certain period in life, the emmetropic, the hypermetropic, the myopic and the astigmatic eye becomes presbyopic.

Presbyopia should therefore be considered as a separate and distinct condition of refraction. The three phases of Ametropia are illustrated by figures 106, 109 and 112.

HYPERMETROPIA.

Based upon the definition given for emmetropia, that for hypermetropia is:—

The Hypermetropic eye possesses equal refraction in every meridian, but the retina is situated between the refracting system and its principal focus.

A number of definitions of hypermetropia may be given, but that just stated, describes the condition fully and in a few words.

For comparison, the definitions of a few well known authorities will be quoted.

"The hypermetropic eye is too short. The retina being too near the optic system, the hypermetrope cannot, without an effort of the accommodation, reunite on the retina parallel or diverging rays." *Tscherning.*

"Hypermetropia may be defined as a condition in which the antero-posterior axis of the eyeball is so short, or the refracting power so low, that parallel rays are brought to a focus behind the retina (the accommodation being at rest). In other words, the focal length of the refracting media is greater than the length of the eyeball." *Hartridge.*

"It is characterized by the fact, that the retina is situated between the dioptric system and the principal focus of the eye." *Landolt.*

"The hypermetropic eye is one which in a state of rest, requires convergent rays, in order to be able to focus them upon the retina." *Landolt.*

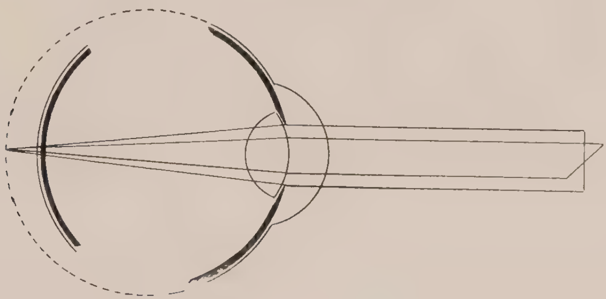

Figure 106.

Sectional view of a hypermetropic eye represented by diagram. Parallel rays of light, lying in two planes at right angles to each other, are shown passing through the refracting system in the vertical and horizontal meridians, and brought to a focus behind the retina. The dotted circle is supposed to pass through the principal focus.

"A hypermetropic eye is one which, in order to see distinctly at a distance, requires a convex glass." *Landolt.*

All of these statements should be carefully studied, for while they vary in describing the same condition, they may be resolved into the same thing. They, however, present the subject from various view points, and comparisons are always valuable in the acquiring of knowledge.

Analyzing the author's definition, it will be found that it explains not only the conditions that exist, but also indicates their *correction* to the student who has mastered Physical Optics.

If its refracting system possesses equal refraction in every meridian, it is capable of creating a correct image, if the retina be situated at its principal focus. As the retina is too near to the refracting system, being inside of its principal focus, the principal focus must be made shorter by increasing the refraction. This indicates the addition of a convex spherical lens.

The correction for Hypermetropia is a convex spherical lens of such power, that combined with the refracting system of the eye, their principal focus will be upon the retina.

Let figure 106 represent a sectional view of a hypermetropic eye. In the vertical and horizontal planes, parallel rays of light are seen to enter the eye, which is in a state of rest, and their principal focus, indicated on the dotted circle, is behind the retina. On the retina they are seen to create a diffused circle, and therefore according to physical optics, they create no clear image.

Read the definition of hypermetropia again, and study this diagram to see what it means. It will also explain the definitions of *Tscherning*, *Hartridge* and *Landolt*.

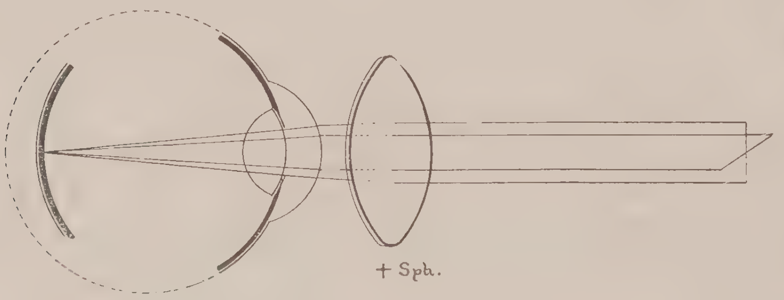

Figure 107.

Diagram to represent the correction for Hypermetropia. The convex spherical lens gives the parallel rays sufficient convergence before entering the eye, to cause them to focus upon the retina.

In figure 107, this hypermetropic eye is illustrated with its *correction* before it. As it is only adapted for convergent rays when its accommodation is relaxed, the required convex spherical lens is shown imposed, changing the parallel rays to convergent rays as they enter the eye, so that they are now brought to a focus upon the retina.

In figure 108, I, represents the pupil of this hypermetropic eye, ts meridians measure + 57. D. II represents its correction, a + 3.00 D. spherical lens; the + 3.00 D. added to the + 57. D. of the eye equals the theoretical emmetropia of + 60. D.

In the correction of hypermetropia, it may be found that the visual acuity may, or may not be normal; it is not infrequent to find vision hyper-acute, being above the normal acuity. Of course it is obtained through an effort of the accommodation.

When the vision is below normal in hypermetropia, a full correction does not always raise the vision to the normal acuity.

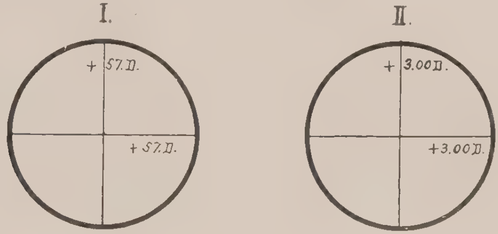

Figure 108.

Two meridians of a hypermetropic eye having + 57.D. of refraction, and a convex spherica lens of 3 00 D. to correct its error. The two combined represent the arbitrary emmetropia of + 60, D.

In the wearing of a correction for hypermetropia, *it is not always* a question of the visual acuity that is involved, but one of relief for the accommodation.

Vision may be up to the normal acuity, or even be hyper-acute, without the correction of the hypermetropia, but the accommodation is required to be exerted to obtain this result, causing nervous strain and ocular distress. Ocular headaches are frequently caused by this condition, and are therefore relieved by wearing the correction.

Under these conditions, it is not a question of what one can see, but how much effort is exerted to see, and its consequences.

The correction for hypermetropia is the strongest convex spherical that will permit of the best visual acuity. A weaker spherical than is thus indicated, requires that the accommodation shall supply the difference. A stronger spherical than indicated, will create an artificial myopia, and thus blur the distant vision..

The Hypermetrope is compelled to use his accommodation, to correct his refractive error, in order to see distant objects distinctly. By reason of the natural association of convergence to accommodation, when he accommodates, the tendency is also to converge. This causes disturbance, and he must do one of two things; either dis-associate convergence, which is likely to cause eye strain, or mentally suppress vision in one eye, which, of course, destroys binocular vision.

If he cannot accommodate for distance, without also converging, his visual lines will meet at a point nearer than the object upon which his vision is "fixed," and he can thus only see it with one eye

Double vision would, under these circumstances, be had, but nature comes to the rescue, and he learns to mentally suppress the vision in one eye.

It is this condition that causes *convergent strabismus or cross eyes.*

The importance of early in life correcting Hypermetropia is thus demonstrated if there is any tendency to the above conditions. *Glasses do not cure cross eyes, neither do prisms*; lenses merely correct the error of refraction and remove the cause.

Convergent strabismus is an unfailing sign of lack of the exercise of the function of vision in the deviating eye. The prevention of convergent strabismus thus means, in many cases, the saving of the sight of the eye.

The term *Amblyopic* is applied to the deviating eye.

The hypermetropic eye is popularly called a "*far sighted eye*," a better and more correct term would be a *weak sighted eye*, because it is lacking in sufficient refraction.

MYOPIA.

In giving a definition of Myopia, the same basis will be used as in defining Hypermetropia. Accordingly:—

The Myopic eye possesses equal refraction in every meridian, but the retina is situated beyond the principal focus of its refracting system.

It will be seen, by comparison of the definition of myopia with that of hypermetropia, that they are just the opposite.

In describing myopia, *Landolt* speaks of it as *axial myopia*, indicating that in the majority of the cases, that the axial length of the eye, along its antero-posterior diameter, is too great.

Tscherning also makes use of the terms axial myopia and axial hypermetropia, and states that a departure of one millimeter in length from emmetropia requires two and a half dioptres of correction. Ac-

cording to this rule, one may estimate the abnormal lengthening of a myopic eye.

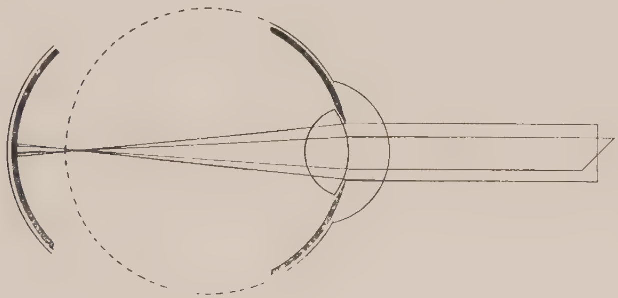

Figure 109.

Myopia, represented by diagram to show a sectional view of the eye. Parallel rays of light are brought to a focus in front of the retina. The dotted circle passing through the principal focus,

The correction of Myopia is a concave spherical lens of such power, that combined with the refracting system of the eye, their principal focus will be upon the retina.

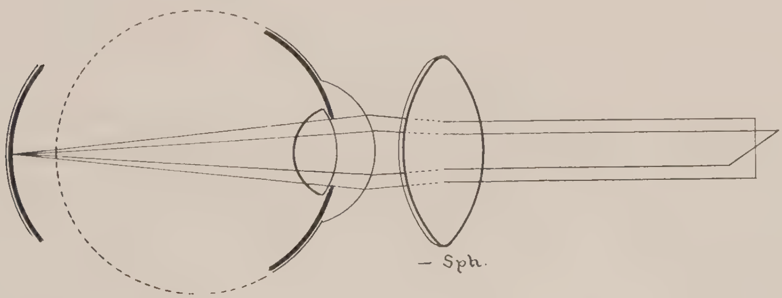

Figure 110.

The correction of Myopia represented by diagram The parallel rays are given a sufficient divergence, by the imposed concave spherical lens, to enable the eye to focus them upon the retina.

Let figure 109 represent a sectional view of a myopic eye, the parallel rays of light are seen to converge at the principal focus, which is in front of the retina, and then diverge to reach the retina as a diffused circle. This is a typical case of axial myopia, the dotted cir-

cle, passing through the optic centre of the refracting system and its principal focus, indicates the lengthening of the globe of the eye.

Figure 110 is intended to show how the correcting lens affects the parallel rays; being a concave lens it causes them to diverge, and as the myopic eye has too short a focus for its length, if the concave lens is correctly adapted, the divergent rays are brought to a focus upon the retina.

In figure 111, I, represents the pupil of this myopic eye, the meridians represented measure + 66. D. II. is its correction, a — 6.00 D. spherical lens. The two combined represent theoretical emmetropia of + 60 D.

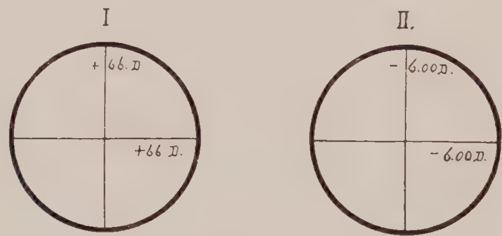

Figure 111.

Two meridians of a Myopic eye, having + 66. D. of refraction, illustrated by I, the — 6. D. spherical to correct the error shown by II.

In myopia the visual acuity is below normal for distance, even when the error is small It differs from hypermetropia in this respect. The reason for this is, that in hypermetropia the refraction that is lacking may be supplied by the accommodation, the eye thus has the power to increase its refraction and obtain a normal visual acuity by an effort. There is no power in the eye, however, by which it can reduce its refracting power, hence, in myopia, the visual acuity is lacking.

In the wearing of a correction for myopia, *it is* a question of the visual acuity that is involved.

The correction for myopia is the weakest concave spherical that will permit of the best visual acuity, which may, or may not, be the normal acuity.

A full correction in myopia does not always raise vision to normal. In high degrees a full correction will not always be tolerated.

There has been much discussion of the advisibility of giving a full correction in myopia; and, judging from the number of myopes who are wearing an under-correction, it would seem that there is a ettled policy of giving under corrections.

The object of correcting errors of refraction is to adapt such a lens to each eye as will, as nearly as possible, create artificial emmetropia, no means of restoring, or creating natural emmetropia, when it does not exist, having been evolved by the ophthalmic surgeon or the oculist up to the present writing. There is no telling what they may do in the future; however, we are at present dependent upon mechanical devices to simulate emmetropic conditions.

A full correction is, therefore, the ideal correction, and the writer believes that in the great majority of cases, *the properly adapted lens will be accepted.*

(Anisometropia and pathological conditions excepted).

No one would think of using a crutch that is too short, in preference to one of the proper length. Glasses are like crutches, a mechanical means to an end.

The greatest cause of dissatisfaction is inaccurately adapted corrections.

In the correction of myopia, it must be remembered, that the visual lines of the uncorrected or under-corrected myope have never been parallel, but always converged.

A full correction, creating parallelism, therefore, involves a readjustment of the relations of accommodation and convergence, just the same as in the correction of hypermetropia.

A Myope is commonly described as *near-sighted*, and the term indicates his inability te see objects at a distance, while the vision for near objects may be extremely good. In fact, the myope has a more acute vision for near point than either the Emmetrope or the Hypermetrope.

ASTIGMATISM.

In an astigmatic eye the refraction is unequal in various meridians.

This definition indicates that the lens for the correction of astigmatism must possess unequal refraction in its various meridians. Such lenses, the student knows, are cylinders, or cylinders combined with sphericals. An astigmatic eye, like an astigmatic lens, has two principal meridians, which are always at right angles to each other. The meridians of greatest and least refraction of the eye are thus at right angles.

Three different conditions may exist to cause astigmatism.

First:—In one of the principal meridians of the eye, parallel rays of light may focus upon the retina, in the other principal meridian, they focus behind the retina.

This condition is called *simple hypermetropic astigmatism.* Its correction is a plano-convex cylinder, the axis being located so that the parallel rays that focus upon the retina, are not refracted in passing through the lens, but those at right angles to the axis, are converged sufficiently for the eye to focus them upon the retina.

Second:—In one of the principal meridians of the eye, parallel light rays may focus upon the retina, in the other principal meridian they focus before the retina.

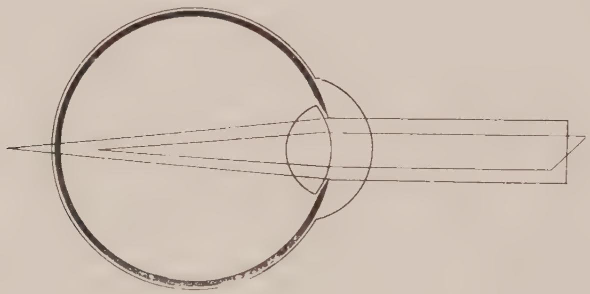

Figure 112.

Sectional view of an Astigmatic eye, illustrated by diagram. Parallel rays traversing the vertical meridian, focus behind the retina; those in the horizontal meridian, focus before the retina. The effect is hypermetropia in the vertical, myopia in the horizontal plane.

This is termed *simple myopic astigmatism.* The correction for this condition of refractive error is a plano-concave cylinder. The axis placed so that it permits those parallel rays that the eye is capable of bringing to a focus upon the retina, to pass undisturbed. At right angles to the axis, it causes the parallel rays to diverge to the degree necessary for the eye to bring them to a focus also upon the retina.

Third:—In one of the principal meridians of the eye parallel rays of light are brought to a focus before the retina, in the other principal meridian, behind the retina.

To this condition of refraction the term *compound astigmatism* is given. In one of the principal meridians a hypermetropic condition

exists while in the other a myopic condition obtains. The correction for compound astigmatism is therefore a plano convex cylinder combined with a plano concave cylinder, their axes being at right angles to each other, and located in the required positions as described in the correction of simple hypermetropic and simple myopic astigmatic error.

It will be remembered that contra-generic cross cylinders may be transposed into equivalent sphero-cylinder lenses, therefore, compound astigmatic corrections may be made by contra-generic cross

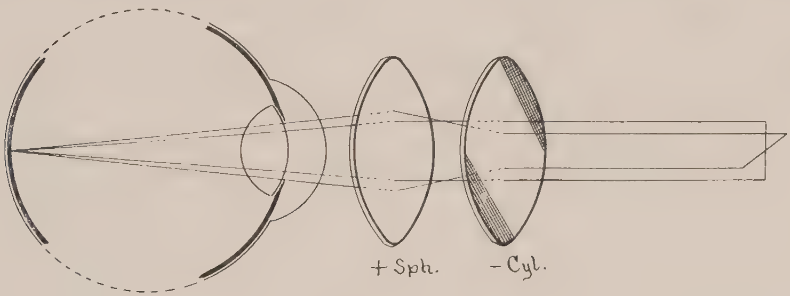

Figure 113.

The correction of Astigmatism illustrated. The concave cylinder gives a divergence to the parallel rays in the horizontal meridian, while in the vertical meridian they pass unaffected. The convex spherical lens then changes the parallel rays in the vertical meridian to convergent rays, and reduces the divergency of those in the horizontal meridian sufficiently for the eye to focus them all upon the retina.

cylinders, axes at right angles; by a convex spherical, combined with a concave cylinder; or, by a concave spherical combined with a convex cylinder

Figure 112 represents a sectional view of an eye in which a compound astigmatic condition exists. Parallel rays in the vertical meridian are brought to a focus behind the retina, showing that in this meridian the eye does not possess sufficient refraction. In the horizontal meridian, the parallel rays focus before the retina, too much refraction existing through this meridian.

Figure 113 illustrates the correction of the condition depicted in figure 112, the correction being made with a convex spherical lens combined with a concave cylinder.

First, the convex spherical is imposed, this corrects the hypermetropia in the vertical meridian, but increases the myopia in the hori-

zontal. Next, the concave cylinder is imposed, axis vertical, to correct the myopia.

In figure 114, I represents the pupil of a compound astigmatic eye. In the vertical meridian the refraction measures + 58. D., in the horizontal meridian, + 62. D. II represents a convex spherical lens of 2 00 D. III represents a concave cylinder of 4.00 D., the axis being vertical. The two lenses in the positions designated, combined with the refracting system of the eye equals + 60. D. in every meridian, or the theoretical emmetropia.

To represent astigmatism with the model shown in figure 103, cut one of the tapered points, either I. or II., a bit shorter than the other.

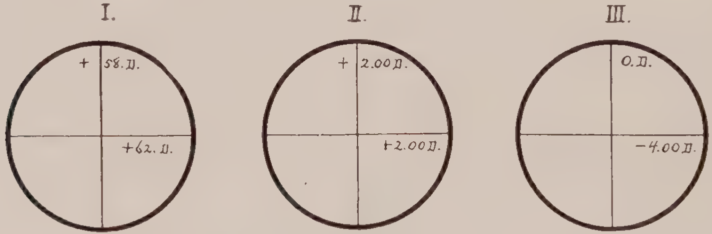

Figure 114.

The principal meridians of an astigmatic eye; the vertical measuring + 58 D. the horizontal, + 62. D., illustrated by diagram I. The convex spherical of + 2.00 D is represented by II; the concave cylinder of — 4 00 D. axis 90° is shown by III. The two lenses, combined with the refracting system of the eye, equal the arbitrary emmetropia of + 60. D, in every meridian.

In Astigmatism, the wearing of a correction involves both visual acuity and effort of accommodation.

The astigmatic person frequently considers that he is near sighted, because by holding small objects, notably fine print, closer to the eyes than the customary reading distance, he is enabled to see more distinctly.

By so doing he creates a larger retinal impression and is thus enabled to see more easily.

In the majority of cases of astigmatism, when a convex cylinder is required for correction, the axis will be found to be at or near the vertical meridian. If concave cylinders are required, the axis will be at or near the horizontal meridian.

Such corrections are said to be *according to the rule.* If convex cylinders are required at or near the horizontal meridian, or, concave cylinders at or near the vertical, they are said to be *against the rule.*

Astigmatism against the rule creates poorer vision than astigmatism with the rule, though the error may be of like degree in both instances.

It is not uncommon to find that the axis of the correcting cylinder for one eye will be in either the vertical or horizontal meridian, while for the other eye it will be in a meridian at an oblique angle to the other.

This is termed *Assymmetry of the axes.*

If the correcting cylinders are of the same species, and both are required in the vertical, or both in the horizontal meridian, they are said to be *symmetrical.* Cylinders of the same species, that are required in meridians that deviate *up* from the horizontal to the same degree, or *down* from the horizontal to the same degree, are also said to be symmetrical corrections.

Corrections for astigmatic errors, where the axes are symmetrical, will be more readily tolerated and accepted, than when the axes are not symmetrical. In cases of assymmetry, it may be necessary to follow a proce ure in correction similar to that in Anisometropia.

A comparison of the various conditions of Ametropia, with Emmetropia, will show that in a static condition *the emmetropic eye is adapted for parallel light rays; the hypermetropic eye for convergent rays; the myopic eye for divergent rays. The Astigmatic eye is adapted to convergent and divergent rays; or, parallel and divergent rays; or, parallel and convergent rays.*

PRESBYOPIA.

Presbyopia is not an error of refraction It is a physiological change that occurs in the eye, resulting in the impairment of one of its functions.

It is a loss of the power of accommodation, which is gradual and progressive, and when the Emmetrope finds that he is unable to accommodate sufficiently to allow him to read comfortably at his accustomed reading-distance, presbyopia is said to have set in.

Presbyopia is that condition in which there is a manifest inability of an eye to accommodate for a near point of nine or ten inches.

It is usual to find that Presbyopia begins about the age of thirty-eight to forty-two years. Some authorities state that it is due to a hardening of the crystalline lens; others, to a weakening of the cili-

ary muscles; still others, to the two conditions combined. Any one of the three causes is acceptable, to all intents and purposes, they are but different ways of stating the same thing.

It is not the writer's intention to go very fully into the subject, as it has been so well treated in numberless works. One point, however, will be emphasized. Presbyopia and hypermetropia are sometimes confused, because the *correction* for hypermetropia is a convex spherical lens, while a convex spherical lens also *compensates* for the loss of accommodation in presbyopia. *They are separate and distinct conditions.*

In giving a lens to compensate for presbyopia, any errors of refraction must first be corrected, and the presbyopic addition made to the correction. All eyes are affected by presbyopic conditions after about the age indicated above. The Emmetrope begins to use a convex spherical glass. The Hypermetrope requires a *stronger* convex spherical for reading than for the correction of his error. The myope requires a *weaker* concave spherical for reading than for distance; he may need no lens whatever for reading; or, he may require a convex spherical for reading. It is dependent upon the degree of the myopia and the progress of the presbyopia. The astigmatic glass wearer requires a convex spnerical added ot his cylindrical correction The definition by *Donders* is:—

"The term presbyopia is therefore to be restricted to the condition in which, as the result of the increase of years, the range of accommodation is diminished, and the vision for near objects is interfered with. For its correction it requires a convex lens of suitable power" According to *Donders*, the following table of the amplitude of accommodation according to age is correct.

Age.	Amplitude (Power)
10	15 00 Dioptres
12	14 00 "
15	12.00 "
20	10.50 "
25	9.00 "
30	7.50 "
35	6 00 "
40	4.50 "
45	3.50 "
50	2.50 "
55	1.50 "
60	1.00 "

The customary distance for the average reader to hold his paper or book, is about fourteen to sixteen inches, and so long as one has five dioptres of accommodation at his command, he has no difficulty. It is not possible to use the whole amount of accommodation one possesses, for any prolonged period; only a certain proportion being available.

The following table will be found to apply in the majority of cases.

Age.	Presbyopic Addition
40	+ 0.50 Dioptres.
45	+ 1.00 "
50	+ 2.00 "
52	+ 2.25 "
55	+ 2.50 "
58	+ 3.00 "

ANISOMETROPIA.

The term *Anisometropia* strictly applies to any difference in the refraction of two associated eyes. It is usual, however, to infer that there is a marked difference, the term being rarely used unless the difference is greater than one dioptre. It is usually applied to de scribe the condition of vision in which error of refraction occurs in both eyes, but of a markedly different degree of the same kind, or a difference in the character of the error. It, however, may be quite properly used where normal refraction occurs in one eye, while an error of refraction exists in the other.

In cases of anisometropia, the visual acuity of one eye is apt to be less acute than the other, and the one having the better vision is said to be the "*dominant eye.*"

When anisometropia occurs, and the errors are not corrected, binocular vision may not exist.

The following procedure in the correction of the condition will be necessary.

If it is found there is a marked difference in the visual acuity of one eye compared to the other, make a note of the one in which the best vision obtains, and give such eye the credit of being the dominant one.

Give full correction for the dominant eye, and go as far as possible toward a full correction for the other as will be consistent with comfortable binocular vision.

A safe rule to follow in such cases will be to make a difference of not more than two to three dioptres in the corrections. The reason for this may readily be demonstrated. With a convex lens of eight dioptres, and one of five dioptres, create two images of the same object upon the same screen, side by side ; it will be seen that the stronger lens creates the smaller image. It is this difference in the size of the retinal images that cannot be tolerated.

Where a high degree of astigmatism exists, and the axes of the correcting cylinders are not symmetrically located, it will not always be possible to give a full correction for the error for both eyes. A full correction may be given the dominant eye, while a portion of the cylinder correction may be given its mate; in some instances the cylinder will have to be omitted for the poor eye ; in some cases the cylinders will not be accepted for either eye.

ASTHENOPIA.

The term *Asthenopia* is derived from the word asthenia, meaning weakness ; without strength. Asthenopia means weakness of the eyes, as manifest by an effort to see, more particularly, when applied continuously to near work, such as reading, sewing, etc.,

Asthenopia may be divided into two classes, accommodative and muscular. The first, is caused by a strain on the ciliary muscles, and may be traced to an excessive effort of the accommodation to overcome hypermetropia or astigmatism. The second, is caused by an imbalance of the motor muscles of the eyes, so that binocular vision is maintained with an effort

Asthenopia in either case may be designated as a muscular weakness, affecting the action of accommodation and convergence, which are intimately associated and dependent upon each other. Asthenopia is indicated when frontal headaches occur, when the print blurs, and the words run together. The person may close the eyes, and, after resting a bit, resume his occupation for a short time, when the phenomena will again recur. Sometimes actual pain will be felt in one or both eyes, that becomes more and more acute as the eyes are forced to continue their labor. There may also be an intolerance to light to more or less degree.

Asthenopia must not be confounded with those cases in which no ametropia or imbalance of the motor muscles exist; yet the person will complain of some or all of the symptoms given. There is a limit to the endurance of all parts of the body, and when that is reached

nature rebels. One may be possessed of absolute mental and physical perfection, yet if either be overtaxed, there is certain to be proof of it.

Some people are unreasonable with themselves in this respect, and expect too much. This is particularly the case with the eyes. They are abused by the great majority, and the conditions of modern living are making more and greater demands upon the eyes.

This same unreasonableness is shown by many who are given glasses to correct some error of refraction. The glasses may bring very poor vision up to normal, affording the wearer visual comfort within reasonable limitations, yet they expect and demand more than could be expected if they were gifted with emmetropic eyes.

By many refractionists, both oculists and opticians, the prescribing of weak power lenses is not advocated, they argue that errors of low degree may and should be ignored, that the eye strain in such cases may be traced to some deeper cause. This may be true to a certain extent. Myopia of a dioptre or so rarely causes trouble enough to drive the person to the ocular refractionist, but by comparison of distant vision with some friend they may learn their deficiency and seek a correction. Hypermetropia may exist to a like amount in both eyes and to quite a considerable amount without causing trouble. It is now acknowledged that small errors of refraction uncorrected, and higher errors under-corrected, are frequently the cause of asthenopic conditions of vision.

Again, it will be frequent to find that anisometropia of a high degree may exist; yet there will be no marked asthenopic symptoms.

The majority of persons who suffer from true asthenopia, or "eye strain," are young people, that is, under the age of thirty. It will be noted that the error of refraction is small in both eyes, but differing in kind or degree; or that one eye may be emmetropic, while the other has a small error.

This is really the secret of the whole trouble, the difference in the small errors. They may be classed as anisometropia of low degree. The reason that asthenopia is developed is, that as the error is small in one or both eyes, that fairly good or even normal vision exists in both; therefore, binocular vision is desired and stimulated. To overcome the errors an effort of the accommodation is exerted, and by reason of the differences of the errors, an unequal effort of the accommodation is demanded, which is contrary to natural law hence, the annoyances of which the person complains. The effort

accommodate unequally also disturb the convergence, creating and adding more trouble.

Asthenopia may be expected under the following conditions :

First. Hypermetropia to about a dioptre or less in both eyes.

Second. Hypermetropia to about two dioptres or less, but of unequal amount in the two eyes.

Third. Emmetropia in one eye, ametropia of small degree in the other.

Fourth. Astigmatism with the rule, and of small degree, but of unequal amount in the two eyes.

Fifth. Astigmatism in one eye, none in the other.

Sixth. Astigmatism against the rule and of very small amount.

Seventh. Those cases in which the correction required is a contra-generic, sphero-cylinder, the extreme of difference in the two principal meridians being one dioptre or less.

It should be remembered that a small amount of astigmatism against the rule causes more trouble than a far greater amount with the rule.

Muscular asthenopia, as a rule, is a sequence to or accompanies accommodative asthenopia. When the refractive errors are corrected both disappear.

CHAPTER VI.

RETINOSCOPY.

The student who has followed the studies outlined in the preceding chapter, has learned the conditions required for normal vision; also, that these conditions are not fulfilled in the majority of cases, owing to errors of refraction.

The various errors that occur have been explained, and the character of the lens required to correct each has been shown, so that the student should be able to prescribe the lens that is adapted to any given condition, *provided he knows what the condition is.*

The next important step is *to learn by what means* he may accurately determine the exact conditions of refraction as they exist in any eye.

Various methods of "*eye testing*" and "*eye examination*" are used to ascertain the refraction of an eye. It will be interesting and instructive to devote a little time to a review of the development of the art of adapting lenses for the eye.

Not many years ago glasses were looked upon as purely a commercial article, to be purchased from the stock of the jeweler, druggist, general-store-keeper, or even the street peddler; each one claiming superiority for his special brand of goods. With the purchaser it was simply a question of trying on pair after pair of glasses until he found one through which he could see with the most satisfaction; he merely drew comparisons between those placed before him. This method differed in no way from that by which shoes were purchased by the same person, viz., try-on-for-a-fit (?).

These glasses were all alike in two respects they were all plain spherical lenses, that were, or were supposed to be, alike in power for each eye.

These self-selected glasses were not always satisfactory, and in many instances the individual found himself unable to obtain any that gave him relief.

This was in a measure due to the fact that there exists in most eyes the error known as astigmatism, which requires for its correction a cylindrical lens Another cause of dissatisfaction with the stock glasses was that they failed to give relief when there was a difference

in the refraction of the two associated eyes, and many of us are now aware that this condition is quite common.

These conditions served to bring the eye specialist into existence. Professional service is now demanded; people will no longer "select" glasses, but wish "advice" as to what they should have.

If the eye could be dismembered, like the optical instruments of man's construction, and the various parts of its refractihg system separately considered, the art of prescribing for its imperfections would no longer be a difficult one.

This is impossible, and as the eye possesses that wonderful adjusting and compensating power, known as the accommodation, which acts involuntarily, and hides more or less the errors, the art of estimating accurately and correcting the visual defects is truly a delicate and difficult one.

Just how reliable the various methods of examination are, as practiced by the oculist and optician, many have reason to know. Each specialist arrives at a different conclusion upon the completion of his examination and prescribes lenses accordingly. If the case is at all a complicated one, two prescriptions will rarely be similar; wide differences existing between the powers of the various spherical and cylindrical lenses, and their combinations, while there is often a difference of many degrees in the location of the axis of the supposedly correcting cylinders.

This variance of opinion is either due to lack of skill upon the part of the specialist or faulty methods employed; presumably the latter, for who can correctly say just how much or what he sees upon the test card of letters after having dozens of lenses placed before his eyes in rapid succession for half an hour or more?

This form of examination is what is known as the "*Subjective Method*," because the information the specialist acquires is obtained through the medium of the individual under examination.

The precision required in accurately determining the condition of the eye's refraction should not alone be based upon the answers given by the patient, but primarily upon facts obtained by the specialist from his own direct observation of the eye itself.

This system constitutes the "*Objective Method*"

If subjective methods alone are used in ocular refraction, there can be no absolute certainty of the accuracy of the correction. The reason for this is that by subjective tests it is impossible to determine *cause*, reasoning from *effect*. In hypermetropia, myopia, or in astigmatism, circles of diffusion occur upon the retina, to create a blurred image and reduce the visual acuity. The proof of this is seen in the

mistakes that are made, myopia being diagnosed when hypermetropia exists; hypermetropia being prescribed for when astigmatism is the error, etc.

By objective examination the refraction may be determined by observation of the operator, and he may thus obtain at least an idea of the possibilities of vision before he asks any questions of the patient. He is enabled to reason from *cause, direct to effects that he can observe.*

A comparison of Subjective Methods with Objective Methods means inaccuracy compared to accuracy.

"Ours is an age of progress." Man has advanced in the arts of life; he has advanced in knowledge.

Within the past ten years the advance in the science of adapting lenses to the correction of errors of refraction has been greater than in the preceding fifty. It has been largely in one direction, viz.: "*Objective Examination*," which is scientific.

"*Subjective testing*," which is not scientific, has not kept pace with it, nor could it be expected, for it has certain limitations that were practically reached by experts in that method years ago.

The progress in Objective Methods has led to greater accuracy in diagnose and given greater satisfaction to the wearers of glasses. This has educated the public to a keener appreciation of the value of good vision and visual comfort, and a consequent greater demand for correctly adapted glasses.

For nearly three-quarters of a century it has been known that under certain conditions the pupil of the human eye, which ordinarily appears to be black, can be made to appear luminous, somewhat like the glow of a cat's eye in the dark.

This phenomena seems to have awakened no investigation until about 1850, when *Cummings* and *Bruecke* developed suitable means for bringing this about in a practical manner.

In 1851, *Von Helmholtz* gave to the world his great discovery, the *Ophthalmoscope*, which served to revolutionize the science of ophthalmology. With it the specialist was enabled to observe the interior of the eye during life, by illuminating its depths.

Previous to the invention of this instrument the human eye's interior was a sealed book until after death.

The glowing appearance of the pupil, observable when the ophthalmoscope is used, did not appear to excite any special interest for many years after the invention of this instrument, although it was early noted that the luminosity of the pupil varied greatly in different eyes.

In 1873, *Cuignet* announced that this difference in appearance was directly traceable to the character of the refraction of the observed eye. *Parent* supplemented *Cuignet's* work, and in 1881 proved conclusively that the refraction of the eye could be positively determined by observing the *character of the retinal reflex as manifested in the luminous pupil.*

The phenomena of the *luminous pupil* is brought about by sending a beam of light into the eye by reflection from a small mirror having a peep-hole at its centre. This light passes through the refracting system and is focused upon a small area of the retina, which in turn reflects a portion of the light back through the peep-hole in the mirror to the eye of the observer, who is thus enabled to study the character of the retinal reflex.

Parent gave the name *retinoscopy* to this scientific method of examination, and the instrument he devised for use in its practice he called the *retinoscope.*

Retinoscopy is endorsed and practised by all the leading eye-specialists of the world, a few opinions regarding its value will be quoted.

Probably one of the greatest living authorities upon the eye is *Dr. M. Tscherning*, who succeeded the great *Javal* as director of the Laboratory of Ophthalmology at the Sarbonne in Paris. He says :

"I have several times emphasized the advantages which retinoscopy with a luminous point presents for the study of optic anomalies of ths eye It also lends itself very well to the ordinary measurement of refraction."

The most prominent English authority, *Dr. Gustavus Hartridge*, says :

"Retinoscopy is deservedly one of the most popular methods of estimating refraction. The chief advantage is that it is entirely objective and is therefore very useful in the cases of young children, in those that are amblyopic, and in maligners; besides, the method is quickly carried out, saving much time in difficult cases of astigmatism. Retinoscopy also enables us to easily detect small degrees of astigmatism, which frequently exist, and but for this method would probably escape notice."

In the correction of visual defects, as in many other achievements, American specialists lead the world. Probably the most widely known authority upon retinoscopy is *Dr. James Thorington*, of Philadelphia. His writings upon the subject have been used as text-books and translated into many languages. He says of retinoscopy:

"With an eye otherwise normal, except for its optic error, and under the influence of a reliable cycloplegic, there is no more exact objective method of obtaining its refraction than by retinoscopy. Its advantages are that the character of the refraction is quickly diagnosed. The refraction is estimated without the verbal assistance of the patient. The correction is quickly obtained. The value of retinoscopy can never be over-estimated in the young, in the feeble-minded, the illiterate, in cases of nystagmus, amblyopia and aphakia. Of all the objective methods of refraction, retinoscopy in the hands of the expert is the most exact."

Retinoscopy may be learned theoretically or practically. There are many Refractionists who are good practical operators with the retinoscope who do not know its theory. There are also many who understand the theory and yet are unable to put it into practical use. It is needless to say that theory and practical application should be learned together.

Anyone may be taught in a few moments to handle the retinoscope so that they may see that it causes the pupil to appear luminous, but it conveys no meaning to their untrained mind.

To attain proficiency in the use of the retinoscope involves special training of the hand, the eye, and the mind of the Refractionist.

The hand must learn to control the instrument so as to project the light beam from it into the observed eye in various ways, according to the existing conditions that may be indicated to the observer.

The eye of the observer must be trained to recognize and differentiate between the various appearances of the retinal reflex, as manifested in the luminous pupil.

The mind must be capable of quickly interpreting the meaning of the observed reflex, and dictating the procedure to estimate the error of refraction if such exists, and its correction.

In order to have a clear understanding of retinoscopy, one should understand the principles upon which the ophthalmoscope is constructed and operated, because the retinoscope is constructed upon the same principles, and used in the same manner, up to a certain point, viz:—the illumination of the retina.

In chapter I, figures 8 and 9, illustrate two conditions under which light is reflected. Figure 8, shows that light rays that strike a surface perpendicularly are reflected back along the path by which they approached; the paths of the incident and reflected rays being the same. Figure 9, shows that when the incident ray forms an

angle with the perpendicular, the reflected ray forms an equal angle with the perpendicular.

In the use of the ophthalmoscope, the conditions shown by figure 8 are followed. Light is reflected through the pupil to the retina, which absorbs a portion of it, but a portion is reflected from the retina outward through the pupil. The operator's eye is so placed behind the ophthalmoscope, that it is in the path of these emergent rays, and receives some of them. The pupil of the observed eye no longer appears black under these conditions, but is illuminated.

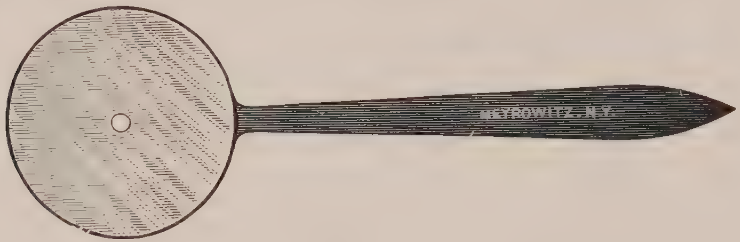

Figure 115.
Plane mirror retinoscope, 42 millimeters in diameter.

Incorporated in the ophthalmoscope are lenses that are used to bring the emergent rays to a focus, so that the observer may see and study the pathologic conditions of the retina.

The retinoscope is simply an instrument to project light upon the retina; it carries no lenses back of the peep hole, such as are used in the ophthalmoscope.

Figure 116.
Dr. Thorington's Retinoscope.

It consists of a mirror which is capable of reflecting the light from some definite source, through the refracting system and pupil of

the observed eye, so that a portion of the retina becomes an illuminated body.

To simplify the subject as much as possible, only the *plane mirror retinoscope* will be considered, and the method of its use explained. The concave mirror will be taken up later.

Figures 115 and 116, will illustrate two forms, and it is simply a matter of personal preference to select either the large or the small mirror; either will do.

The light source has always been a perplexing problem in retinoscopy. In reading over numerous articles upon the subject, the reader will be surprised at the differences of opinion upon this point. All kinds and conditions of light are advocated, with various screens and shades. In addition to this, the position of the light with reference to the patient and the retinoscope, is the subject of a variety of opinions. This only serves to confuse the student.

The writer will no doubt cause a storm of criticism when he states that too much importance is attached to these conditions.

It is desirable that the light source should be brilliant, with an even area of illumination. An electric lamp of the incandescent type, with sanded globe is quite satisfactory. One of sixteen candle power will serve for most cases, or if more light is required, a thirty-two candle power may be used. If electric light is not available, a Welsback, or better still, a Kern type of incandescent gas burner is excellent.

The light should be placed behind the patient, at the level of the eyes, and a little to one side; either side will be correct.

The important thing to do is to have the light so placed, that when the observer takes his position facing his patient, as shown in plate 135, he may be able to project the light, reflected by his retinoscope, directly into the eye of his patient. His object is to get the light into the eye so that he may observe the *emergent rays.*

It is not necessary to confuse the student by elaboration of the character of the entering rays, that may be taken up later; it is only necessary to consider that they enter under fixed conditions, with the plane mirror, *and emerge in accordance with the refraction of the eye.*

It is known that objects are seen by the light that they send to the eye, either by radiation (luminous bodies), or reflection (illuminated bodies).

If the retina were a luminous surface, light would be emitted from the eye, and the pupil would present a luminous appearance instead of appearing black. If this were true, and the emitted light

were of sufficient intensity, it would not be necessary to illuminate the retina by projecting light upon it, and the retinoscope would have to be constructed upon quite a different plan.

Not being a luminous surface, it is necessary to make the retina an illuminated surface, in order that some light may be reflected outward through the pupil.

The ophthalmoscope and the retinoscope are both used to illuminate the retina.

In the use of the ophthalmoscope, the operator studies the appear-

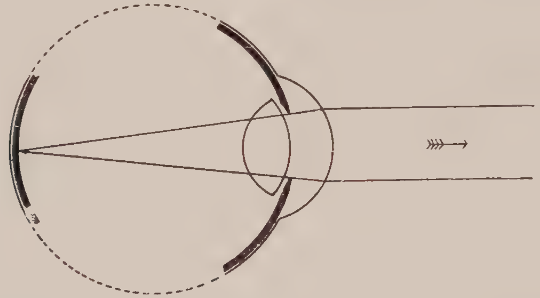

Figure 117.

Direction of emergent rays from an Emmetropic eye in a static condition, under observation with the retinoscope. Emergent rays parallel.

ance of the retina and its component parts in search of pathologic conditions. The refraction of the eye may also be estimated with the ophthalmoscope.

In the use of the retinoscope the Ocular Refractionist studies the character of the emergent rays reflected from the retina, because he knows that according to the character of the refracting system of the eye, and its relative position with regard to the retina, *the emergent rays take different directions.*

It has been taught that the emmetropic eye, in a static condition, is adapted to focus *parallel rays* of light upon its retina, because the retina is situated at the principal focus of its refracting system. See figures 95 and 102.

If light be reflected from the retina of an emmetropic eye in a static condition, *the rays will emerge parallel.* See figure 117, the arrows indicate the direction of the rays.

The hypermetropic eye, in a static condition, is adapted to focus *convergent rays* to a focus upon its retina, because the principal focus of its refracting system is situated at a point behind the retina. See figures 106 and 107. If light be reflected from the retina of a hypermetropic eye in a static condition, *the rays will emerge divergent*. See figure 118. The degree of divergence will depend upon the length of the antero posterior diameter. The nearer the retina is situated to the refracting system the greater will be the divergence. Another way of considering the condition is; that of two hypermetropic eyes,

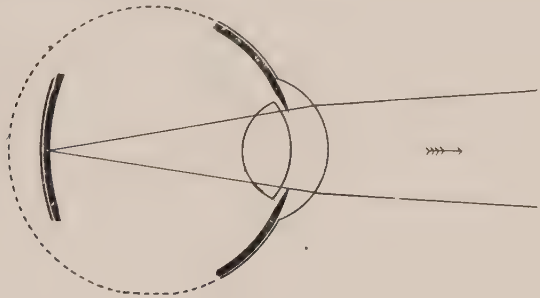

Figure 118.

Direction of emergent rays from a Hypermetropic eye in a static condition, under observation with the retinoscope. Emergent rays divergent.

the one having the greater error of refraction, will give the greater divergence to the emergent rays. This is a significant point to get clearly in mind, because it has an important bearing upon the actual practice of retinoscopy, as will be demonstrated later on.

The myopic eye is adapted to receive and focus upon its retina, only *divergent rays* of light, because its retina is situated beyond the principal focus of its refracting system. See figures 109 and 110.

Light rays reflected from the retina of a myopic eye *have a convergence as they emerge.* See figure 119.

The degree of convergence of the emergent rays is dependent upon the axial length of the eye, and the location of the point at which these rays converge, or focus, is dependent upon the same condition. The nearer the retina is situated to the principal focus, the less convergent the emergent rays will be.

The focus of the emergent rays from a myopic eye is designated

as its far point (P.R.). Of two myopic eyes, that in which the higher myopia exists, the nearer will its far point be. The student must fix this fact clearly in mind as it is of the utmost importance.

In the astigmatic eye, owing to its unequal power of refraction in various meridians, the emergent rays take different directions.

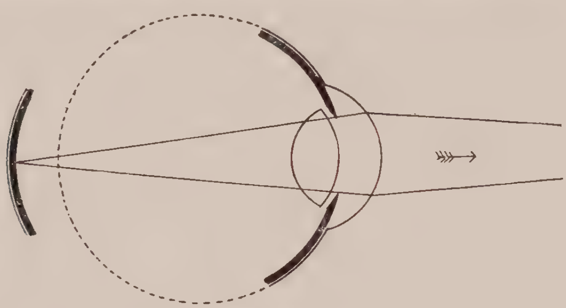

Figure 119.
Direction of emergent rays of light from a Myopic eye, under observation with the retinoscope. Emergent rays convergent.

In simple hypermetropic astigmatism, the rays emerge parallel in one meridian, while in the meridian at right angles to it, they emerge divergent In compound hypermetropic astigmatism, the rays emerge divergent in all meridians, but more so in some than others.

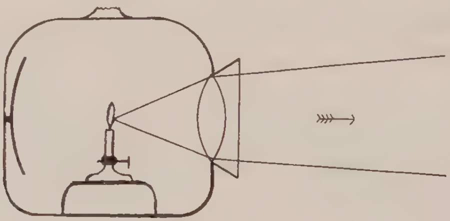

Figure 120.
Plan of bicycle lamp, showing convex spherical lens, location of flame, direction of emergent rays.

The meridians of greatest and least divergence are always at right angles to each other.

In simple myopic astigmatism, the rays emerge parallel in one meridian, while in the meridian at right angles to it, they emerge

convergent. If the eye possesses compound myopic astigmatism, the rays emerge convergent in every meridian, but more so in some than others. The meridians in which the greatest and least convergence occurs are always at right angles to each other.

The emergent rays from an eye that possesses mixed astigmatism, are convergent in some meridians, divergent in others. The meridian in which the greatest ivergence occurs is always at right angles to the meridian in which the greatest convergence occurs. Figure 112 shows how parallel rays entering an eye that has mixed astigmatism are brought to a focus in its two principal meridians. The emergent rays from the same eye would diverge in the vertical meridian, and converge in the horizontal meridian.

In order to make as clear as possible, the conditions governing the emergent rays of light from the eye, the principle upon which a bicycle lamp is constructed will be explained, and the emergent rays from such a lamp, and those from an eye, will be compared.

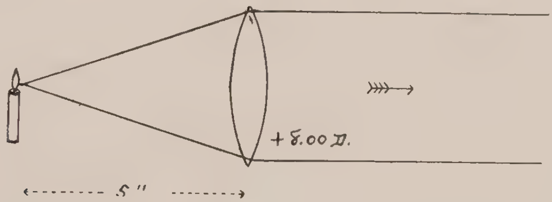

Figure 121.

Lighted candle p'aced at the principal focus of a convex spherical lens. Emergent rays parallel.

Let figure 120 represent the plan of a bicycle lamp. The lens is a double convex spherical, with the flame of the lamp situated just inside of the principal focus; this gives to the emergent rays only a slight divergence. Behind the flame is placed a concave mirror that reflects the light that strikes the back of the lamp, forward through the lens. The nearer the light is placed to the lens, the wider divergence is given to the emerging rays.

Comparison of figure 120 with figure 118, shows that the emergent rays from the bicycle lamp, and those from a hypermetropic eye are both divergent; therefore, the conditions of hypermetropia are similar to those of the lamp, viz:—the light source is inside the principal focus of the refracting system.

Another comparison may be drawn between this lamp and the eye. Looking into the aperture of the lens, it appears black until the lamp is lighted, when it appears luminous. Looking into the aperture of an eye it looks black until light is projected upon the retina, which reflects a portion of it outward through the pupil, rendering it luminous.

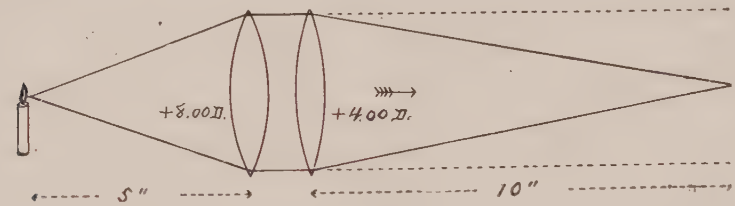

Figure 122.

Emergent parallel rays brought to a focus by interposing a convex spherical lens.

At this point the student is advised to refer to figures 38, 39, and 41, to refresh his memory upon the principles they illustrate; viz:—*principal focus and conjugate foci.*

According to the laws of conjugate foci, the following experiments may be made.

Let figure 121 represent a convex spherical lens of eight dioptres (+ 8.00 D. S.), with a lighted candle placed at its principal focus, five inches. The light rays strike the lens divergent and emerge from it parallel. If it is desired to bring these parallel emergent rays to a focus again at any certain distance from the lens, say ten inches, without changing the relative positions of the candle and lens,

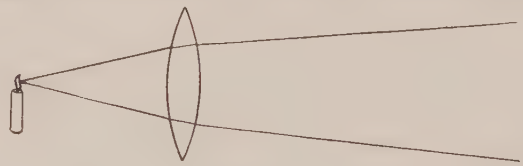

Figure 123.

A lighted candle situated at a point inside the principal focus of a convex spherical lens. Emergent rays divergent.

it will only be necessary to place a convex spherical lens of the required focal length, (+ 4.00 D.), a four dioptre, to intercept the rays as they emerge from the first lens. The second lens will cause them to converge and focus ten inches away. See figure 122.

The conditions represented by figure 121 may be compared to those in an emmetropic eye. By the procedure illustrated by figure 122, the conditions that exist in a myopic eye are created.

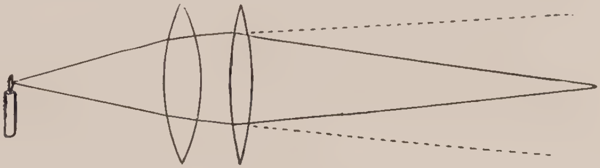

Figure 124.
Diverging emergent rays brought to a focus by interposition of a convex spherical lens.

Let figure 123 represent a convex spherical lens, the lighted candle is nearer the lens than its principal focus, consequently the diverging rays that strike the lens, emerge divergent. In order to render the emergent rays parallel, another convex lens would have to inter-

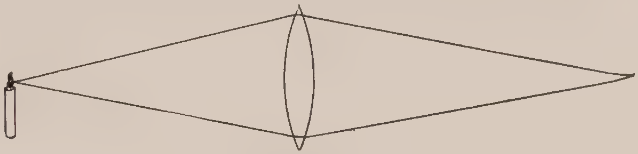

Figure 125.
Alighted candle placed beyond the principal focus of a convex spherical lens, emergent rays convergent.

cept them. If it should be required to bring them to a focus, a still more powerful convex lens would have to be interposed between the first lens and the point at which it is desired they should be brought to a focus. See figure 124.

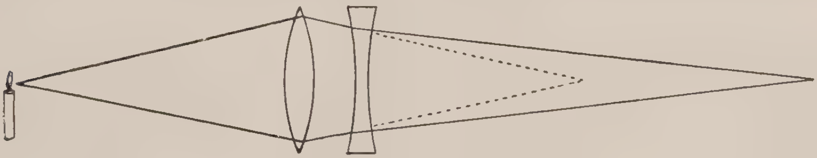

Figure 126.
Converging emergent rays rendered less convergent by interposing a concave spherical lens.

Figure 125 represents the candle placed beyond the principal focus of the convex lens, the emergent rays are seen to converge as they emerge from the lens.

Suppose the point at which they focus is eight inches from the lens, and it is desired that they should focus 20 inches away. This may be brought about by interposing a concave lens of the proper power (— 3.00 D.) to lessen their convergence, so that they will focus at the required point. See figure 126 The dotted lines in figures 126, 124 and 122, indicate the direction the emergent rays would have taken had the second lenses not been interposed.

Compare the conditions illustrated by figures 117 and 121 to see that they are alike. The same is true of the conditions illustrated by figures 118 and 123; also, figures 119 and 125.

A study of the optical conditions illustrated by the figures from 117 to 126 inclusive, reveals that through the aid of the retinoscope it is possible to calculate the *conjugate foci* of the eye, making use of a lens, or combination of lenses, of *known dioptric value.*

From these *known lenses*, as a basis for calculation, the unknown dioptric value (conditions of refraction) of the eye under observation may be determined with more or less accuracy.

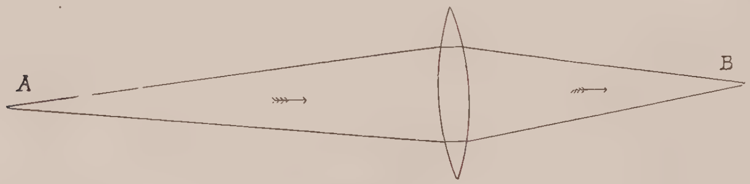

Figure 127.
Conjugate foci. A, luminous point; B, focus.

When the actual dioptric conditions of the eye are thus made known, its errors of refraction, if any exist, may be corrected with accurately adapted lenses.

In the practice of retinoscopy, the Ocular Refractionist really learns the character of the retinal image, when observed through the medium of the retinoscope at any given working distance, which is erect or inverted according to the refraction of the eye

This phase of the subject may be ignored by the stndent at this time, as it may be confusing, it is merely mentioned so that the writer may not be accused of teaching false doctrines.

Only the effects of light and shadow movement in the luminous pupil created by the use of the retinoscope need be studied at first.

To bring up the subject of conjugate foci at this point will be advisable to illustrate a vital point.

It is known that light that is sent to a convex spherical lens from a luminous point, so that the rays enter the lens divergent and emerge convergent, that they focus at another point. The luminous point and the focal point are termed conjugate foci, and their locations are interchangeable.

Let figure 127 illustrate this proposition. A, is the luminous point; B, the focal point on the opposite side of the convex spherical lens. If the luminous point be moved to B, the focal point will be located at the position A.

In the calculation of conjugate foci, it will be seen that it is necessary that the rays should converge as they emerge from the lens. The author has coined a term to designate these conditions, viz:—*positive conjugate foci.*

In explanation of this term it may be stated that it is customary to consider that a convex spherical lens has a *positive focus*, see figure 38, while a concave spherical lens has a *virtual focus*, see figure 54.

Reference to figures 117, 118 and 119, shows that only the rays from a myopic eye emerge convergent, therefore, the myopic eye has *positive conjugate foci.* Those from the hypermetropic eye emerge divergent, and from the emmetropic eye parallel; hypermetropic and emmetropic eyes have *virtual conjugate foci*

By referring to figures 122 and 124, it will be seen that by interposing convex spherical lenses, *positive conjugate foci may be created.*

In the practice of retinoscopy, the Ocular Refractionist locates the myopic far point of the eye.

If the eye is myopic this may be done without interposing any lenses whatever. If the eye is not myopic, the myopic condition may be created by interposing the necessary lens or lenses, to locate the artificial far point at a definite distance.

This definite distance from the eye under observation, which the operator selects, is called the working distance.

The proper working distance in retinoscopy has been the subject of much discussion and diversity of opinion, which tends to confuse the student. If the meaning of the term is thoroughly understood it need not be perplexing.

In the majority of cases it will be found that a working distance of forty inches, which is equal to one metre, will be most convenient It will simplify the matter of making allowance for the working distance because forty inches is equal to the focus of a one dioptre lens. It is conveniently near to the patient, so that lenses may be changed in the trial frame by the operator without leaving his position.

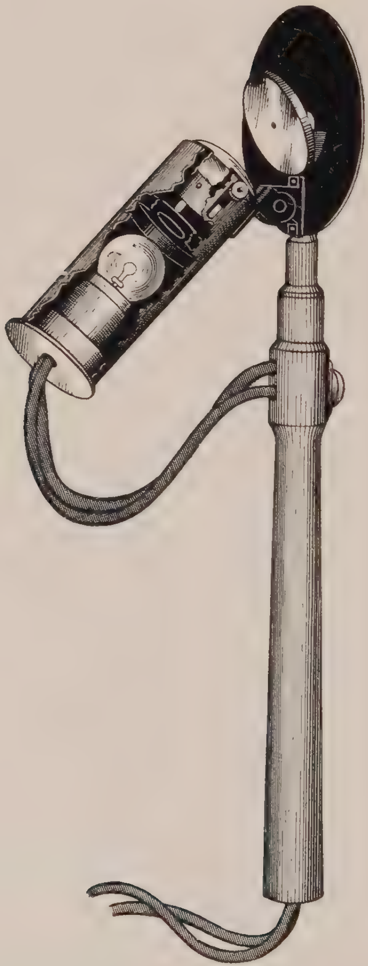

Figure 128.
The De Zeng self luminous retinoscope.

It is sufficiently far away to enable the operator to note the slight changes in the appearance of the reflex as the reversal point is neared.

If the pupil is small, as frequently occurs with elderly people; or the reflex is dull and indistinct, which may be due to a high degree of error of refraction or a dense retinal pigment, a nearer point than forty inches may have to be selected, for the working distance.

These points will be more fully explained in describing actual practice.

Fortunately the introduction of the luminous retinoscope, see figure 128, carrying its own source of light, simplifies the working conditions and affords the refractionist ample freedom to choose any working distance best suited to the case in hand. The position of the light source may be ignored because it is always under control. The intensity of the light may be regulated, and increased to such brilliancy that a reflex may be obtained under all conditions.

It is hoped that the author has made it sufficiently clear that any distance may be selected as the working distance; but conditions are imposed that bring the location of the working distance within certain well defined limits. This knowledge will come with practice.

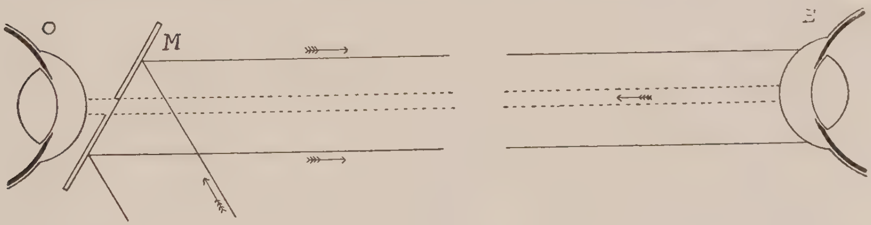

Figure 129.

An emmetropic eye under observation with plane mirror retinoscope, working distance one metre. O. eye of observer; M, retinoscope; E, eye under examination. The unbroken lines represent entering parallel rays; the dotted lines represent the emergent rays, also parallel.

An earnest endeavor has also been made to make the subject of conjugate foci as clear as possible, and the student is urged not to pass beyond this point until he has the matter clearly in mind. The importance of this cannot be overestimated, because the theory and practice of retinoscopy is founded upon the physical laws governing conjugate foci.

Let figure 129 represent an eye, E, under examination with a plane retinoscope M; the position of the operator is one metre, or forty inches distant; his eye is represented by O which is behind the

retinoscope. Figure 129 represents the conditions that occur if the eye E be emmetropic. The parallel rays represented by the unbroken lines, are seen to be reflected from the plane mirror M, into the eye E. As the eye is emmetropic the rays that are reflected from its retina emerge parallel, and some of them, represented by the dotted lines, reach the eye O of the observer as parallel, through the peep-hole in the mirror.

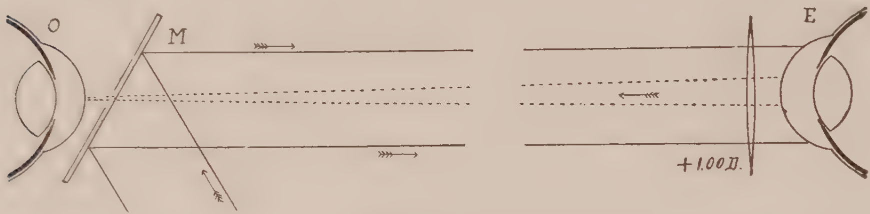

Figure 130.

Emergent rays from an emmetropic eye brought to a focus at the working distance of one metre, by a convex spherical lens of one dioptre. See dotted lines.

Suppose it is desired to converge the emergent parallel rays shown in figure 129, so they will focus at the position of the observer 40 inches distant.

As it is known that a convex spherical lens of one dioptre will bring parallel rays to a focus at forty inches, if such a lens be placed

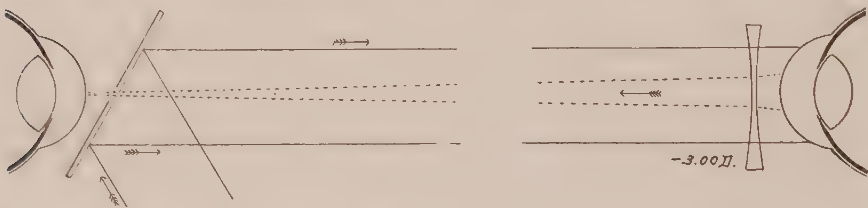

Figure 131.

Emergent rays from an eye, myopic to four dioptres, brought to a focus at the working distance of one metre, by a concave spherical lens of three dioptres.

before this emmetropic eye, as illustrated by figure 130, the emergent rays will focus at the observer's eye O. The dotted lines represent the emergent rays, and show that their direction is changed from parallel to convergent by the one dioptre convex lens interposed.

If the eye under observation, shown in figure 130 were myopic to

one dioptre, the emergent rays would focus at the observer's eye at forty inches distance *without interposing any lens.*

Let figure 131 represent an eye that is myopic to four dioptres, the emergent rays would focus at a distance of ten inches, its far point. If the observer with the retinoscope were forty inches away, in order to bring them to a focus at this position, it would be necessary to impose a concave spherical lens of three dioptres. This lens is seen to render the emergent rays less convergent, as shown by the dotted lines, figure 131. The conditions are now similar to those shown in figure 130.

Figure 132 represents an eye that is hypermetropic to two dioptres, under observation with a plane retinoscope, the observer being again one metre distant. The emergent rays are divergent but

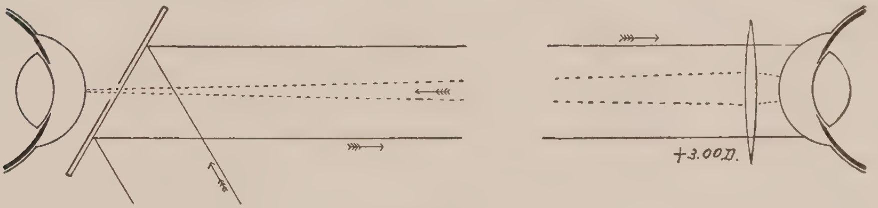

Figure 132.

Emergent rays from an eye, hypermetropic to two dioptres, brought to a focus at the working distance of one metre, by a convex spherical lens of three dioptres.

by interposing a convex spherical lens of three dioptres they are converged and focussed at the observer's eye. These conditions are now similar to those shown in figure 130. The direction of the emergent rays, indicated by the dotted lines, is changed by the convex lens.

It will be seen, from the foregoing, that in the practice of retinoscopy, if the eye under examination be myopic to one dioptre, or more, that its far point may be determined with the retinoscope. If it is not myopic, by imposing certain required lenses, a myopic condition may be created for the emergent rays and the location of the far point determined.

In explanation of the above, a simple analogy may be drawn. Suppose one has a quantity of small blocks, exactly an inch square and one-eighth of an inch in thickness, and it is desired to place them in piles of twenty-four each, making the height of each pile three inches. The simplest way to do this would be to count out twenty-four and stack them into one pile, as a measure, see A, figure 133.

The pile B is too short, and the pile C too tall, as the dotted line shows. Some must be taken from C, and more added to B.

If someone should ask the height of the piles B and C as they were originally, and say that the blocks in each must not be counted, nor the piles measured, the problem could be solved by counting the number it was necessary to add to B, and the number it was required to take from C. These, compared to the known quantity in A, will serve as a basis from which to calculate the numbers in B and C, and the height of the two original piles.

Thus, in the practice of retinoscopy, if a certain lens value is required to be imposed to focus emergent rays to a definite point, one may calculate the unknown refraction of the eye.

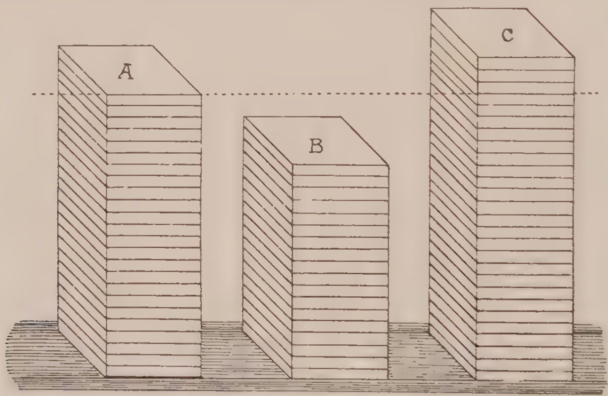

Figure 133.
Diagram to represent the meaning of the term, "Working distance in retinoscopy."

These propositions will no doubt seem simple enough to the student, the bringing to a focus of the emergent rays to a definite point, by the interposing of certain lenses under certain conditions; but, he may, and doubtless will ask—How is one to know, when one observes an eye with the retinoscope, whether it is emmetropic, myopic or hypermetropic?—The answer is: the appearance of the luminous pupil varies according to the different conditions of refraction.

Thus far the *theory* of retinoscopy has been explained, the next step will be to take up *actual practice and working conditions*

The study of retinoscopy has brought into use a simple device called the model eye, which is a most valuable aid to the student, who

may practice upon it by the hour without its entering any protest of fatigue. A description of it in the inventor's own words will suffice. It is shown in figure 134.

"The eye is made of two cylinders of cardboard, one slightly smaller than its fellow, to permit slipping easily into the other. Both cylinders are well blackened inside. The smaller cylinder is closed at one end, and on its inner surface is placed a colored lithograph of

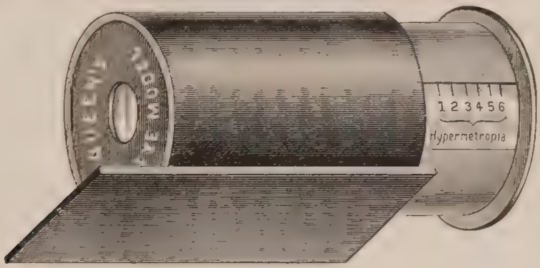

Figure 134.
Model eye for the study of retinoscopy.

the normal eye ground. The larger cylinder is also closed at one end, except for a central round opening, ten millimeters in diameter, which is occupied by a plus twenty dioptre lens."

"On the side of the small cylinder is an index which records emmetropia, and the amount of myopia and hypermetropia according as it is pushed into or drawn out of the large cylinder."

In other words, the model eye can be "set" to represent emmetropia, myopia to six diopters or less, and hypermetropia to six diopters or less; by merely sliding the two cylinders so as to change the axial length of the eye. By placing a cylinder lens from the test case before the model eye, an astigmatic condition may be created and studied.

These cardboard model eyes are inexpensive and the student is advised to procure four of them for the purpose of practice. Nearly all knowledge is drawn from comparisons, and in the study of retinoscopy the opportunity to compare effects with the model eyes set to represent different conditions of ametropia, affords valuable practice.

The author wishes to impress upon the student one most important point In the practice of retinoscopy *learn to be methodical*, for it is a scientific test that is based upon well defined laws, and to

obtain the best results it cannot be accomplished with careless methods. *Attention must be given to details of position of the patient, operator and the light. See that lenses are clean* and properly set in trial frame, *which must be set to the proper inter-pupillary distance.* Other details will be explained in their proper place.

Retinoscopy is often condemned by those who, through their own careless practices, are unable to acquire proficiency.

To "make haste slowly" is also good advice. Retinoscopy cannot be learned in a few days, nor a few weeks. This statement is not intended to discourage the student, nor should it dampen his ardor. *One may learn in a very short time to recognize the different errors of refraction*, but the little niceties of operating the instrument are acquired with *practice*. All cases of myopia present similar phases, so do all cases of hypermetropia; astigmatism of like character shows similarity in all instances; but no two eyes present exactly the same appearance under the retinoscope. Differences in the size of the pupils; differences in the density of the retinal pigment; differences in the aberration of the refracting systems; varying effects of the accommodation, all act to change the appearance of the retinal reflex.

To overcome these difficulties one must have practice. The old saying—"Practice makes perfect"—certainly applies to retinoscopy, only it may be modified to—Practice leads to proficiency; therefore, take the model eyes and *practice, practice, practice.*

It may be well to mention that if the refractionist has an error of refraction in his own eye, so that his own visual acuity is impaired, he should wear his correction in using the retinoscope, otherwise he may fail to recognize what he sees. The wearing of one's correction may prove annoying to some extent, owing to the reflections that occur on the surfaces of the lenses, but a little experience will enable the operator to overcome this. The above does not mean that the accommodation of the operator must be taken into consideration, as in the use of the ophthalmoscope, but merely that the best possible visual acuity is essential to the Refractionist so that he may be able to recognize what he sees.

In the practice of retinoscopy some operators advocate the use of a cycloplegic, and contend that the test is useless without it. The author disputes this claim, and contends that not only is a *cycloplegic not necessary*, but that more satisfactory results are obtained *without* it. While a cycloplegic holds the accommodation in abeyance, it dilates the pupil, exposes the peripheral portions of the crystalline lens

and discloses its aberrations that are concealed, or cut out by the iris, under normal conditions. The accommodation may be held in check by other means. This is a fortunate circumstance for the optician, who is not qualified nor permitted to use a cycloplegic. It also meets with the approval of the majority of people who object to "drops in the eye."

Plate 135.
Working conditions with the retinoscope at one metre distance, showing correct positions of patient and operator.

If the test be conducted in a darkened room, the pupil will dilate sufficiently to obtain a good reflex. The refracting room need not be in absolute darkness, particularly if using the self-luminous retinoscope. The author's refracting room is painted a dull-surface black, but the partition does not extend clear to the ceiling, so that a suffused light fills the room which is only comparatively dark.

The only direct source of light in the room during the retinoscopic test must be that used in connection with the instrument.

Plates 135 and 136 are made from photographs taken in the author's operating rooms; a photograph faithfully reproduces every detail, and these plates will serve better than any diagram to illustrate actual working conditions.

The patient is seated in a revolving chair, which permits of the proper adjustment for height, *so that the eyes of the patient and operator are on a level with each other.*

In plate 135, the patient and operator are shown one metre apart. *The allowance for working distance will therefore be one dioptre.*

Patient and operator face each other squarely, the patient directing his look just over the top of the operator's head and at some object as far away as possible.

The method of holding the retinoscope is plainly seen, the instrument being close to the right eye of the observer. The instrument used in this instance is a luminous one; the beam of light is seen projected from the retinoscope into the left eye of the patient. To the patient's right, and just above his head, will be seen a black sheet iron cylinder attached to the partition; it contains a sanded electric lamp which emits a steady light through the circular opening in the cylinder. This light is used with the forms of retinoscope illustrated by figures 115 and 116. This sheet iron cylinder makes a very satisfactory screen for the lamp, the top an bottom being closed. Any tinsmith will be able to make one at a small cost.

This same light may also be used with the ophthalmoscope.

To control the beam of light projected from the retinoscope requires considerable practice. It may be supposed that it is a simple thing to direct the mirror so that the light will reach the eye of the patient. The student need not be surprised to find that it is quite difficult at first; in fact, that he cannot locate the eye with it. To avoid any such evidence of lack of skill, the student should not attempt the human eye until he has had some practice on the model eyes. A good scheme for practice will be to paste a small bit of paper, about

an inch in diamer, on the wall at the level of the eye and try to locate it by projecting the light beam upon it.

The expression—" to rotate the mirror "—that is so frequently used in describing the handling of the instrument is apt to be mislead-

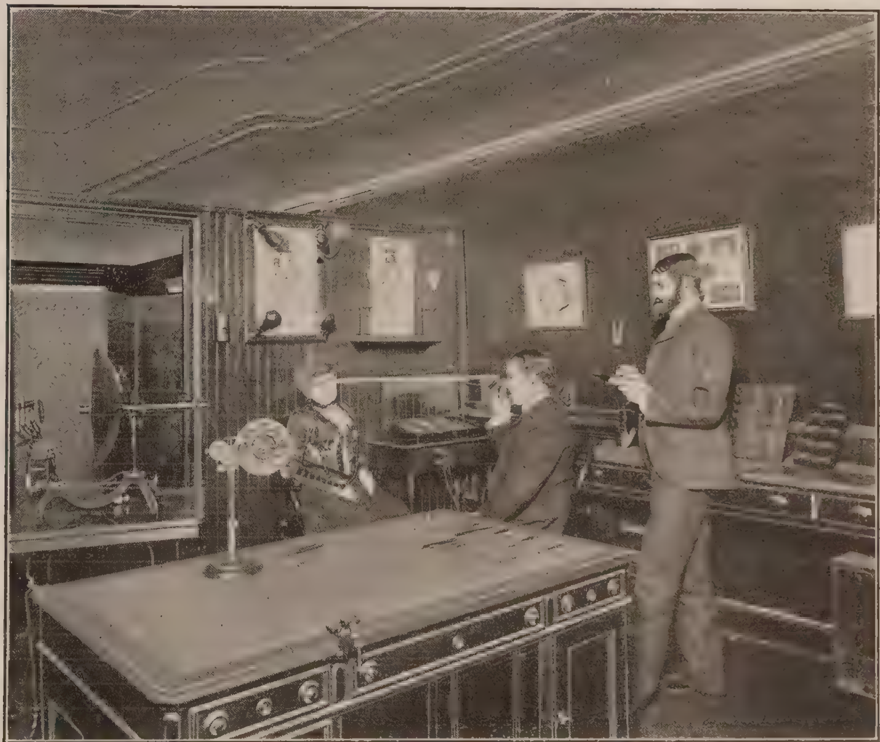

Plate 136.

The retinoscopic examination under actual working conditions, from a photograph in the author's refracting room.

ing; while it is entirely correct, it may make the point clearer to state that the mirror should be tilted or inclined.

Plate 137 illustrates the correct method of holding the retinoscope. The handle is lightly but firmly grasped, close up to the mir-

ror; the instrument is held squarely before the eye and touching the forehead. Either eye may be used as preferred by the operator.

The mirror is inclined in various directions, or tilted, by a movement of the wrist alone, the head to be held motionless. This directs the movement of the light beam; a very slight movement is sufficient to cause the light to pass across the face of the patient.

Plate 137.
Correct method of holding the retinoscope.

Some operators have a habit of holding the retinoscope firmly against their forehead, and tilt the mirror by a movement of the head, to the right and left, up and down, etc. This style of operating appears awkward, the operator bobbing his head in an apparently aimless fashion; it gives one the appearance of one of the porcelain figures representing a Chinese Mandarin.

It is just as well to cultivate a "clean-cut style" of operating, which is not difficult; it pays well, because it inspires confidence in the patient to have the Refractionist display an easy manner in his work, denoting familiarity with it, and skill.

Plate 138 illustrates the light beam from the retinoscope projected directly upon the eye. In the illustration it is seen to create a *circular spot of light* upon the face, about two inches in diameter.

This is called the "Light Area."

If the retinoscope be tilted slightly, this light area will of course move also, and *always in the same direction as the mirror is tilted.*

Plate 138.

Light beam from the retinoscope directed full upon the eye under observation. The "light area" upon the face, and the luminosity of the pupil, or "retinal reflex," is clearly shown in contrast with the darkness in the pupil of the other eye. This plate was made from a photograph from life. The reflex is seen occupying the entire pupillary area. This also serves to illustrate the "choked" appearance of the reflex when the "point of reversal" is located with the retinoscope.

If the light area is made to pass across the pupil, following a straight line, it is said to have made a "transit of the pupil."

A transit of the light area thus means, that in passing across the pupil, one of the meridians of the eye is followed. By means of the transit of the light, the observer is enabled to estimate the character of the refraction of the eye *in that one particular meridian traversed.*

If the eye be emmetropic, hypermetropic or myopic, it possesses

equal refraction in every meridian; therefore, in determining the refraction in one meridian, the refraction of the eye is obtained.

Plate 138 shows the pupil of the eye under observation, located at the centre of the light area; which will be the case when the light beam from the retinoscope is directed full upon it. The pupil is seen to be illuminated, the contrast between it and the darkness of the pupil of the other eye being quite marked. The area of light in the pupil is brighter than the light area upon the face, so that it is not difficult to see it.

Under these conditions the pupil is said to be "*luminous.*" It is created by some of the light from the retinoscope entering the eye through the pupil, and then reflected outward by the retina through the pupil again.

The light seen in the luminous pupil is called the "retinal reflex."

The light from the retinoscope in passing through the refracting system of the eye is focused upon a comparatively small area of the retina. Around this illuminated spot the retina is in darkness, the areas of light and darkness being clearly defined and in contact with each other. This may be demonstrated by focussing light with a strong convex spherical lens upon a dark surface.

Looking at plate 138 again, and noting that the pupil of the eye under examination is luminous, while the pupil of the other eye appears in darkness; it is obvious that the reflex is created by the retinoscope, and *if the light area is passed off the pupil*, it will again appear in darkness the same as the other.

If this is done, the light area being made to pass off the pupil slowly, if the eye possesses spherical ametropia, that is, myopia or hypermetropia, the retinal reflex does not disappear instantly from the pupil but moves off slowly. It is followed by an area of shadow, so that an area of light and shadow is seen in the pupil at the same time. See plates 139, 141, 142 and 143.

This area of light and shadow in the pupil is merely the reflex of the light area surrounded by darkness that is created upon the retina.

The form in which the light reflex joins the shadow, denotes the character of the refraction of the eye.

If the shadow shows a crescent shape edge adjoining the light, it indicates spherical ametropia, viz:—myopia or hypermetropia.

Plate 139 represents hypermetropia or myopia as indicated by the retinoscope. The method of determining which of the two exists in each case, will be explained a little later on. In plate 139 the reflex is seen to shade off gradually into the shadow, the line of separation

being crescent in form. The form of the crescent varies with the degree of the error.

Plate 140 shows an entirely different appearance of the reflex and shadow in the pupil, the line separating the two being straight, the reflex assuming the appearance of a bright band of light across the area of darkness.

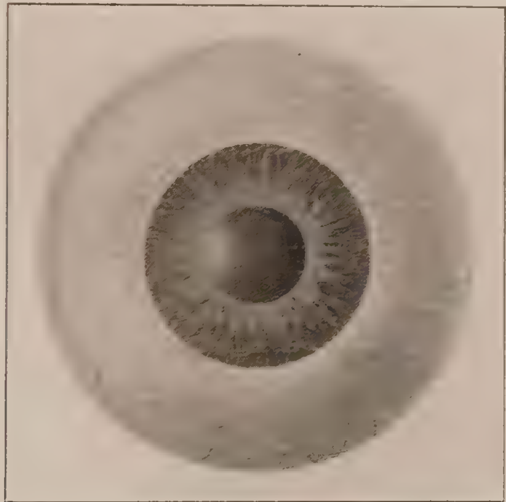

Plate 139.

Spherical ametropia as indicated by the retinoscope. The light area in the pupil shades gradually into its following shadow. The line of demarkation being of crescent form.

This light band is typical of astigmatism, which is thus indicated by the retinoscope.

The breadth of the light band, the definition of its edges, and its brilliancy, varies with the degree of the error.

The direction of the light band indicates the location of the axis of the cylindrical lens required to correct the error.

The direction of the light band thus indicates one of the principal meridians of the refracting system of the eye, the other principal meridian is always at right angles to the light band. The value of the retinoscope will thus be seen, in not only detecting astigmatism, but also in locating the axis of the correcting cylinder.

As previously stated, comparisons form a most valuable method of obtaining knowledge, and this applies particularly well to the practice of retinoscopy.

Having obtained four of the model eyes illustrated by figure 134, set one of them according to its index to represent *emmetropia.*

The index of the model eye will be found to read as follows :—

6 5 4 3 2 1 0 1 2 3 4 5 6
MYOPIA. HYPERMETROPIA.

The figure 0 represents emmetropia.

Set the second one to represent *myopia of one dioptre*; the third to represent *myopia of four dioptres;* and the fourth to represent *hypermetropia of two dioptres.*

Plate 140.

Astigmatism as indicated by the retinoscope, the typical band like appearance of the reflex in the pupil. The direction of the light band indicates the location of the two principal meridians of the refracting system of the eye, therefore; the location of the axis of the correcting cylinder lens.

The object of setting the eyes to represent these particular conditions of emmetropia, and ametropia of definite character and amount is this : Figures 129, 130, 131 and 132 *illustrate theoretically*

these definite conditions, and it is desired to show *how they appear to the Refractionist under actual working conditions with the retinoscope.*

A small shelf should be fastened to the wall on a level with the operator's eye, upon this he may conveniently place the model eyes for practice. Place the four model eyes, set as previously directed, upon this shelf, side by side and in the order named. Now measure accurately a distance of one metre (forty inches) directly in front of them. This will represent the point at which the operator's eye must be situated for the examination. A very convenient procedure will be to fasten to the side wall, a rule marked off in inches; one may be obtained at a small cost; or a mark of some kind may be placed on the wall or floor to indicate the position.

The operator should now be in the position illustrated by plate 135, and his model eyes should be in the position of the patient. He is now ready for actual work.

Direct the light beam from the retinoscope *full* upon the first eye, set to represent emmetropia. By the term—*full upon the eye*—the condition illustrated by plate 138 is meant; that is, *the pupil is in the centre of the light area on the face*; in plates 141, 142 and 143 the pupil is *not* in the centre of the light area because the light beam is not full upon the eye.

When the light beam is directed full upon the eye and held steadily in this position, the black appearance of the pupil will instantly give place to an illuminated appearance, which, as previously stated, is called the *luminous pupil*, or the *retinal reflex*, usually shortened to simply *the reflex*. This appearance of the reflex in the pupil is very clearly illustrated in plate 138, which was made from a photograph from life. Compare the appearance of the pupil of one eye, illuminated by the retinal reflex, with the pupil of the other eye which appears black.

Now direct the light full upon the second eye, and hold it steadily. This eye represents myopia of one dioptre. The same appearance of the pupil will appear as with the first eye. Submit the third and fourth eyes to the same conditions, and though they represent myopia and hypermetropia respectively, they too present the same appearance as the other eyes under like conditions.

Now we know that these four eyes under observation represent four different conditions of refraction, three of them being errors; yet they all show a similar appearance when the beam of light from the retinoscope is directed full upon them, and *held steadily so.* The reflex in the pupil in each instance shows an even amount of illumin-

ation and fully occupies the pupillary area. The only difference that may be detected will be a difference in the brilliancy of the reflex, but this may be difficult to see, and would not serve to indicate the character of the refraction.

When the light area is full upon the eye, as illustrated by plate 138, it is said by the author to be in a *primary position*, when it is in a position illustrated by plates 141, 142 or 143 it is said to have moved to a *secondary position*.

Suppose the light area on the face be caused to move completely across the pupil, it is said to have made a *transit of the pupil*.

If the light beam from the retinoscope be swept across the model eyes, arranged side by side, so that the light area makes a transit of the pupil of each, it will be observed that in *three* of them there is *a movemen of the reflex in the pupillary area*. In one of them there will be *no movement of the reflex*.

The eye in which there appears to be no movement of the reflex will be the one set to represent *myopia of one dioptre*. This absence of movement of the reflex is said to be a *choked* appearance of the reflex. *It occurs when the eye of the observer with the retinoscope is at the myopic far point of the eye under examination;* the area of illumination on the retina of the eye under examination, and its image at the eye of the observer are conjugate to each other, see figure 127.

During the transit of the light area, in the pupils of the three other eyes the reflex will be seen to move also. When the light area reaches its primary position, see plate 138, the reflex will be seen to illuminate the *whole pupillary area*. When it reaches a secondary position, see plate 141, it will be observed *that only a portion of the pupillary area is illuminated*, the remainder being in darkness. This area of darkness in the pupil which appears as the light area passes to a secondary position is called the "*shadow*;" it is from this that the term—"Shadow Test" is derived.

Plate 141, represents an eye under observation, in which the light area has passed from the primary position to a secondary position, the direction in which the light area moved being *to the left*. The reflex in the pupil has also *moved to the left*, the right half of the pupil being occupied by the following shadow. The direction of the movement of the reflex has therefore been the same as that of the light area; in other words, the movement of the reflex is "*with*" that of the light area.

Plate 142, shows the light area in a secondary position, the direction of its movement being *to the right*, the movement of the reflex

has also been *to the right*, or "*with*" that of the light area.

Plate 143, shows the light area in a secondary position, the movement being *to the right*, the movement of the reflex in this instance is *to the left*, or opposite to that of the light area. It is said to be "*against*" that of the light area.

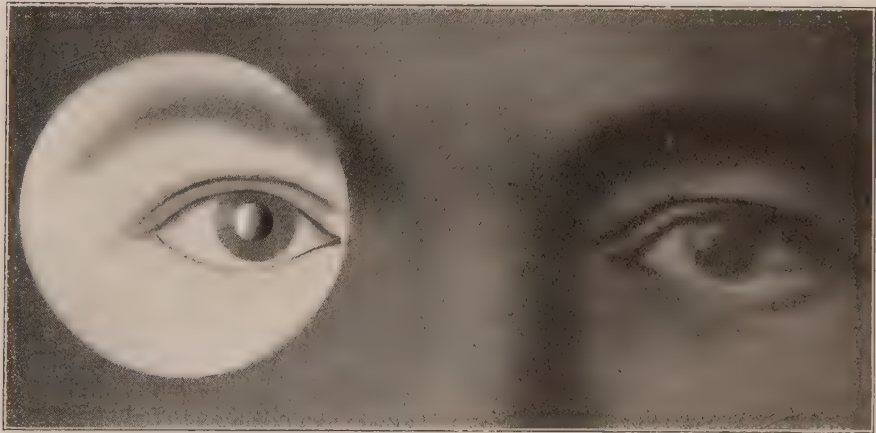

Plate 141.

Hypermetropia as indicated by the retinoscope. The light area on the face is passing off the pupil to the left, the movement of the reflex is also to the left in the pupil, with the movement of the light area. The shadow is seen following the reflex in the pupil.

It is this movement of the reflex, with or against the movement of the light area, that determines the character of the refraction of the eye

The conditions illustrated by figures 141, 142 and 143, occur when the plane mirror retinoscope is operated.

Now sweep the light beam from the retinoscope across the four model eyes again, and observe how the reflex moves in each. In the first eye, set to represent emmetropia, the movement will be "with"; in the second eye set to represent myopia of one dioptre there will be no movement, the reflex being "choked;" in the third eye, set to represent myopia of four dioptres the movement will be "against"; in the fourth eye set to represent hypermetropia of two dioptres the movement will be "with". From this the following rule may be established.

With a plane retinoscope, at a working distance of one metre,

myopia of over one dioptre shows movement against that of the light area Hypermetropia, emmetropia or myopia of less than one dioptre shows movement with that of the light area. Myopia of one dioptre shows no movement of the reflex.

Bear in mind that these experiments with the model eyes just outlined are the practical operations involved in the theory illustrated by figures 129, 130, 131 and 132.

In first operating the retinoscope let the transit of the light be slow, rapidity is acquired with practice. If the untrained eye and mind are called upon to see and interpret the movement of the reflex, it will be found difficult because the eye will see more quickly than the mind can interpret. Mental perception is slower than ocular perception.

Having observed that the movement of the reflex in the first eye

Plate 142.

Hypermetropia as indicated by the retinoscope. The light area and reflex both passing to the right.

is "with", interpose a + 1 00 D. S. and the reflex will be found to be "choked" because the emergent parallel rays of the emmetropic eye will be brought to a focus at the working distance of one metre. In the third eye, the movement of the reflex "against" will be "choked" by interposing a — 3.00 D. S, the emergent rays which converged to a focus at ten inches being brought to a focus at the

working distance of forty inches. The fourth eye in which the movement of the reflex is "with" will be "choked" by interposing a + 3 00 D S., the emergent rays which diverged being brought to a focus at the working distance of one metre.

Plate 143.

Myopia as indicated by the retinoscope. The light area on the face is passing off the pupil to the right, while the reflex is moving to the left in the pupil.

This movement of the retinal reflex in the pupillary area, with or against the movement of the light area, is governed by the following conditions With a plane retinoscope, if the image observed is erect, the movement will be "with"; if the image is inverted the movement will be "against". When no movement occurs, the reflex being "choked", the reversal point of the image is indicated, therefore:—

In the examination of an eye with a plane retinoscope if the reflex movement is against, the observer is beyond the reversal point; if the movement be with, the observer is inside of the reversal point. It will be seen that the object of the retinoscopic examination is to locate the reversal point at some definite working distance.

Roughly estimated it is usual to say that movement against indicates myopia, movement with hypermetropia, the plane mirror being used. If a concave mirror retinoscope be used the movement of the reflex will be the reverse of that with a plane retinoscope. Move-

ment with indicating myopia, movement against indicating hypermetropia.

The next experiment will be to set one of the model eyes to represent myopia of two dioptres, another to represent myopia of five dioptres. Pass the light beam across the two at the same rate of movement and observe the rate of movement of the reflex in the two, also the comparative brilliancy of the reflex. It will be found that while the rate of movement of the light area is the same, that the rate of movement of the reflex will be slower in the eye having the greater error. The reflex will be brighter in the eye having the lesser error.

Set the other two eyes to represent hypermetropia of one dioptre and four dioptres respectively and perform the same experiment; a similar condition will be noted The movement of the reflex will be slower in the case of the greater error, and the reflex will be less brilliant in the eye having the greater error. From this the following observation may be made.

The greater the error of refraction, the slower the movement of the reflex; and the less brilliant will it be. The student should study these differences so that he will learn when a high or a low power lens is indicated, it will save much time to him and annoyance to his patient, to be able to approximate the correcting lens by the rate of movement of the reflex. This too is acquired with practice.

Suppose we consider an every-day case. The retinoscope indicates hypermetropia, the movement being "with". As the student has not had sufficient practice to be able to tell by the rate of movement if the error is great or small, it will be suggested that he place a + 1.00 D. S. before the eye and again observe the reflex. The movement is still with. What has he now learned? That it is a true case of hypermetropia, because if it had been myopia of less than one dioptre the reflex would now be against; while if it were emmetropia the reflex would be choked. Replace the + 1.00 D. S. with a + 2.00 D. S. The movement is still with. With a + 3.00 D. S. the movement appears choked. In order to make sure, try a + 3.50 D. S. If + 3.00 D. S. did choke the reflex, with the + 3.50 D. S. there will be movement against, showing that the reversal point has been passed.

In order that one may be sure that the reflex is choked, it is always well to go beyond the reversal point, and then drop back to the next lens weaker than the one which reversed the movement of the reflex.

If the movement be choked by the + 3 00 D. S. it is known that the emergent rays are now converged to the eye of the observer at the working distance, in this instance at forty inches. Suppose this was the right eye and that it required a + 3.50 D.S. to choke the reflex in the left eye. Now make an allowance for the working distance by adding — 1.00 D. S., because if it required the above power convex sphericals to converge the emergent rays to forty inches, one dioptre less would render them parallel, or create conditions similar to emmetropia. The problem would then be as follows:—

O. D. + 3.00 D. S.	Retinoscopic findings.
Add — 1.00 D. S.	Allowance for one metre working distance.
O. D. + 2.00 D. S.	Correction for error of refraction.

O. S. + 3.50 D. S.	Retinoscopic findings.
Add — 1.00 D. S.	Allowance for working distance of one metre
O. S. + 2.50 D. S.	Correction for error of refraction.

Another case will be cited for illustration.

The person is of advanced age and the pupils are quite small. When viewed with the retinoscope at the usual working distance, one metre, the reflex appears dull, and its movement uncertain. Approaching nearer to the patient, say twenty-six inches, the direction of the reflex seems to be with, indicating hypermetropia. + 3.00 D.S. interposed renders the reflex more brilliant and increases its rate of movement; it is more easily observed however at twenty-six inches than at forty inches, so twenty-six inches is selected as the working distance.

It is found that a + 6.50 D. S. appears to choke the reflex in each eye, to render it certain + 7.00 D. S. is interposed, when it is found that the direction of the reflex is reversed, showing that the reversal point has been passed. The estimate of the error and its correction will be as follows:—

O. U. + 6 50 D S.	Retinoscopic findings.
Add — 1 50 D. S.	Allowance for working distance.
O. U. + 5.00 D. S	Correction for error of refraction.

The allowance for working distance is one and a half dioptres because it is the equivalent of twenty-six inches.

It may be observed here that in hypermetropia the pupils are apt to be smaller than if the error be myopia.

In examination of another case the reflex observed from a one

metre distance indicates myopia, the movement being against that of the light area. In this instance the following is the estimate of the error:—

O. D. — 3.50 D. S.	Retinoscopic findings.
Add — 1.00 D. S.	Allowance for working distance.
— 4.50 D. S.	Correction of error of refraction.
O. S. — 2.75 D. S.	Retinoscopic findings
Add — 1.00 D. S.	Allowance for working distance.
— 3.75 D. S.	Correction of error of refraction.

A — 4.00 D. S. reversed the movement of the reflex in the right eye, and a — 3.25 D. S. reversed it in the left eye.

In making the allowance for the working distance of one metre a — 1.00 D. S. is added. In the first observation of the eyes it was noted that the emergent rays focussed between the observer and the eye under observation. The concave lenses rendered these convergent rays less convergent and established their focus at forty inches. By the addition of one dioptre more concave spherical they would be rendered parallel.

By some writers on retinoscopy the operator is advised to subtract the value of the working distance in hypermetropia, and add the value of the working distance in myopia.

It will be found less confusing to remember if the rule is made to always add — 1.00 D. S. for a working distance of one metre. If the working distance be twenty inches, of course add — 2.00 D. S., if twenty-six inches add — 1.50 D. S., etc.

Plate 144 illustrates a nice point in retinoscopy, the estimation of the point of reversal in myopia without the use of a lens.

The preceding cases have been explained to show that the point of reversal, or myopic far-point, could be definitely located at a given working distance. If an eye be myopic to one dioptre, the reflex will appear as choked at forty inches. If an eye be myopic to more than one dioptre, its far-point is somewhere inside of forty inches; if the working distance be moved to this point, by the operator approaching nearer to the eye than the one metre distance, the choked appearance will be manifest when the far-point is reached, no matter how near the eye it may be.

For example; if the eye be myopic to four dioptres, its far-point will be ten inches away. At forty inches the reflex will move against the movement of the light area, but if the operator approach to ten

inches as a working distance the reflex will appear as choked. Nearer than ten inches it will be reversed.

If an eye be myopic to eight dioptres, its reflex will appear as choked at five inches; if myopic to three dioptres, choked at thirteen inches. etc.

From this it will be observed that in myopia if the operator will locate the far point of the eye and then measure his working distance, he may determine the refraction without any lens whatever.

Plate 144 illustrates a method for working in this manner. The author is seen operating the retinoscope with his right hand, in his left is held a spring tape measure with an automatic catch. The patient holds the end of the tape-measure against his cheek, the one inch mark being in line with his eye. The end of the tape-measure is made fast to a convenient handle as seen in the illustration. The working distance is read off on the tape-measure, when the reversal point is found, and quickly transposed into dioptres. This illustration is given in order to show the accuracy that is possible with the method, and therefore its value. In practice it will not be necessary to apply this in all cases, but if the operator even roughly estimates the myopic far point by approaching the eye, and then working back to his one metre distance, he will save himself much time, and his patient will be saved annoyance by his ability to select approximately the correcting lens at the outset of his examination.

The student is advised to practice along this line on the model eyes, having someone make the eye myopic to an unknown amount by selecting some convex lens whose value is unknown to him and imposing it before the eye.

In order to be sure that the reflex is perfectly choked in either hypermetropia or myopia, a transit of the light should be made in various meridians of the eye. It *may* be found that while a choked appearance is noted in some meridians that in others there will still be a movement; this denotes irregular refraction.

Thus far only spherical errors have been considered. As in these cases the refraction is alike in every meridian it makes no difference what meridian the transit of the light follows. When the refraction of one meridian is ascertained, all are known.

In astigmatic conditions the procedure is obviously quite different. In neutralizing an unknown astigmatic lens, it is necessary to locate its two principal meridians and then ascertain the dioptric value of each.

In astigmatism it is necessary to locate the two principal meri-

dians of the eye, then measure the refraction of each.

The astigmatic band seen in the reflex, illustrated in plate 140, indicates the position of the two principal meridians. One of them will be parallel to the direction of the band, the other will be at right angles to it. In plate 140, the principal meridians are indicated in

Plate 144.

Method of locating the myopic far point in myopia without the aid of a lens by measuring the working distance with a tape measure held by patient and operator. From a photograph in the author's refracting room.

the vertical and horizontal directions. In measuring the refraction of an astigmatic eye, the transit of the light must follow these two meridians and no others.

Plate 145, illustrates astigmatism at an oblique axis, the light band is seen passing from the pupil and followed by the shadow, the straight band of separation is clearly shown.

Suppose that in the retinoscopic examination of an eye the appearance of the refl·x in the pupil is similar to that shown in plate

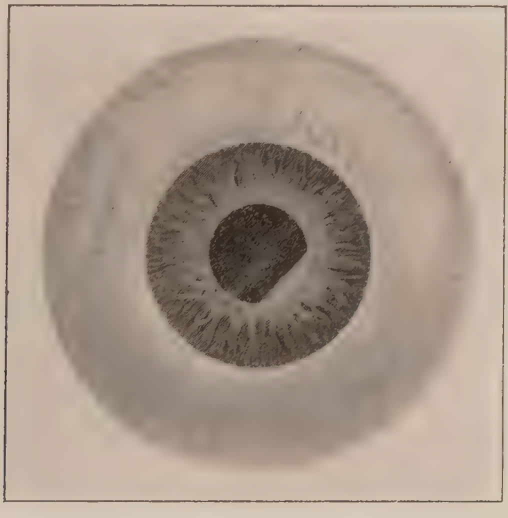

Plate 145.
Astigmatism at an oblique angle. The light band is seen just leaving the pupil.

140. If a transit of the light in the direction of the band, shows slight movement *with* the movement of the light area, hypermetropia is indicated in that meridian. If a transit of the meridian at right angles to the band shows movement of the light band *against* the movement of the light area, myopia is indicated in that meridian. The working distance being one metre.

Interpose a + 1.00 D. S , and it will be assumed that this chokes the reflex in the horizontal meridian. Now the vertical meridian showed myopia before any lens was interposed, the + 1.00 D. S.

therefore renders this meridian more myopic. No matter, leave the + 1.00 D. S. before the eye.

Concave value is wanted in the vertical meridian, but it is desired not to disturb the horizontal meridian in which the reflex is choked by the + 1.00 D S. This may be accomplished by using a concave cylinder and placing the axis parallel to the meridian in which the reflex is choked; that is, parallel to the direction of the light band, or its axis horizontal. It will be assumed that a — 2.50 D. Cyl. chokes the reflex in the vertical meridian, in fact, with the + 1.00 D.S. $\bigcirc$ — 2.50 D. Cyl. ax. 180°, the reflex is choked in all meridians of the pupil.

What is understood to be the condition now? Simply this, the rays of light that emerged from the eye irregularly, are now converged regularly, and brought to a focus at the working distance of forty inches.

In making the allowance for the working distance the same procedure is followed as in spherical errors of refraction, add — 1.00 D.S. to the retinoscopic findings. In this instance:—

+ 1.00 D. S. $\bigcirc$ — 2.50 D. Cyl. ax. 180°	Retinoscopic findings.
— 1.00 D. S.	Allowance for working distance of one metre.
0 $\bigcirc$ — 2.50 D. Cyl. ax. 180°	Correction for error of refraction.

It will be seen that in this particular case the correction is reduced to a plane concave cylinder. The allowance for working distance does not alter the cylinder, it only affects the spherical.

This point is frequently confusing to the student, he does not see why it should not also affect the cylinder. If he will stop to think that the combination of spherical and cylinder was required to bring the irregularly emergent rays to a regular convergence and focus, he will see that this regularity of direction must not be disturbed in estimating the combination of spherical and cylinder required to make the emergent rays parallel.

The following examples may serve to make this clear. Working distance (W. D.) 1 metre.

+ 2.00 D. S. $\bigcirc$ — 3.00 D. Cyl. ax. 165°	Ret. Find.
— 1.00 D. S.	W. D. 1 metre.
+ 1.00 D. S. $\bigcirc$ — 3.00 D. Cyl. ax. 165°	Correction.

+ 3.50 D. S. $\bigcirc$ — 1.25 D. Cyl. ax. 15°	Ret. Find.
— 1.00 D. S.	W. D. 1 metre.
+ 2.50 D. S $\bigcirc$ — 1.25 D. Cyl. ax 15°	Correction.

— 1.50 D. S. $\bigcirc$ — 0.75 D. Cyl. ax. 90°	Ret. Find.
— 1.00 D. S.	W. D. 1 metre.
— 2.50 D. S. $\bigcirc$ — 0.75 D. Cyl. ax. 90°	Correction.
— 3.50 D. S. $\bigcirc$ — 2.25 D. Cyl. ax. 10°	Ret. Find.
— 1.50 D. S.	W. D. 26 inches.
— 5.00 D. S. $\bigcirc$ — 2.25 D. Cyl. ax. 10°	Correction.
— 1.50 D. Cyl. ax. 180°	Ret. Find.
— 1.00 D. S.	W. D. 40 inches.
— 1.00 D. S. $\bigcirc$ — 1.50 D. Cyl. ax. 180°	Correction.
+ 2.00 D. S. $\bigcirc$ — 1.00 D. Cyl. ax. 80°	Ret. Find.
— 1.00 D. S.	W. D. 1 metre.
+ 1.00 D. S. $\bigcirc$ — 1.00 D. Cyl. ax. 80°	Correction.

In cases of simple, and compound myopic astigmatism, little difficulty is experienced in making the retinoscopic estimate of the error

If it be simple myopic astigmatism, a plane concave cylinder may be used to create the choked appearance of the reflex, the axis being placed parallel to the direction of the light band. Or, knowing that in the meridian parallel to the light band the eye measures emmetropic, the refraction of the meridian of error, at right angles to it, may be measured by imposing a concave spherical.

If the case be one of compound myopic astigmatism, the meridian of least error will be corrected by a concave spherical, the other principal meridian will require a concave cylinder in addition to the spherical already imposed.

The cases that tax the skill of the refractionist are those that belong to the following classes; simple, and compound hypermetropic astigmatism, and mixed astigmatism. The reason for this is, that the action of the accommodation must be controlled. In myopic astigmatism this annoying factor is in the majority of instances absent.

The secret of success lies in the use of a method similar to that employed in the subjective method known as the "fogging system," viz:—the use of convex lenses.

The method will be most readily understood if the procedure in a case of mixed astigmatism be explained.

Refer to figure 140 again and assume that in a transit of the horizontal meridian the movement is with, indicating hypermetropia. A transit in the vertical meridian shows the reflex movement against, showing myopia. In such a case three different methods of locating

the myopic far point with combinations of lenses may be followed, all of which will be correct. They are as follows:

+ Spherical ○ — Cylinder.
— Spherical ○ + Cylinder.
— Cylinder ○ + Cylinder.

While any one of these three combinations if properly estimated, will be correct, and the optical effect of all be the same, provided they are properly worked out, still there is a preference as to which one to follow. It is the first one given, a convex spherical combined with a concave cylinder.

By first imposing the convex spherical that chokes the hypermetropic movement, the desire to accommodate ceases and the accommodation is relaxed. The convex spherical should remain before the eye and the required concave cylinder be added to correct the other meridian.

From this procedure the following rule may be established.

In mixed astigmatism, correct the hypermetropic meridian with a convex spherical first, then correct the myopic meridian with a concave cylinder.

Example.

	+ 2.75 D S ○ — 4.00 D. Cyl. ax. 40°	Ret. Find.
Add	— 1.00 D. S.	Allowance for W. D. 40 inches.
	+ 1.75 D. S. ○ — 4.00 D. Cyl. ax. 40°	Correction.

In compound hypermetropic astigmatism, the same practice should be followed according to the following rule.

Correct the meridian of most hypermetropia with a convex spherical first, then correct the other meridian, which has been made myopic with a concave cylinder.

Example.

	+ 4.00 D. S. ○ — 1.00 D. Cyl. ax. 180°	Ret. Find.
Add	— 1.00 D. S.	Allowance for W. D 40 inches.
	+ 3.00 D. S. ○ — 1.00 D. Cyl. ax. 180°	Correction.

This should be transposed to its equivalent generic value.

+ 2.00 D. S. ○ + 1.00 D. Cyl ax. 90°

It may be said that the same result could be obtained by correcting the meridian of least hypermetropia first with a convex spherical, and then the other meridian with a convex cylinder, arriving at a generic formula at first. So it could be done, but by making the estimate with a contra-generic formula, which is easily transposed into its gen-

eric equivalent, the results may be more quickly and accurately obtained; the accommodation being relaxed, or rather, held in check.

It will be a valuable rule to follow, to always impose a convex spherical lens whenever any hypermetropia is manifest, even though it may be of small amount compared to the manifest myopia.

Contra-generic formula of convex spherical combined with concave cylinder, makes reliable results possible with the retinoscope without the aid of a cycloplegic.

There will be noticed in some cases a peculiar appearance of the reflex; when the light beam is full upon the eye, the light area being in the primary position, the reflex may appear as illustrated by plate 140, the characteristic astigmatic light band. When the light area is moved to a secondary position, the light band may appear to be divided into two bands, that approach or separate as the light transit is made in a meridian at right angles to their direction. The effect created is called the "scissors motion" of the reflex. It is due to irregular astigmatism and usually indicates a contra-generic correction of convex spherical combined with a stronger concave cylinder.

CHAPTER VII.

PRACTICAL HINTS FOR THE PRACTICE OF RETINOSCOPY.

IT is advisable to interpose lenses before both eyes at the same time in locating the reversal point at the working distance. By this it is meant that it is not desirable to use a blank disk over the associated eye while making the retinoscopic examination of the other. Impose the necessary lenses before each eye, working toward the required corrections simultaneously.

If the case under examination be hypermetropia, simple or compound, one eye may have a convex spherical imposed that is stronger than is required for the correction of the error, while the proper correction for its associated eye is being made. This tends to relax the accommodation and incidently to expand the pupils of both eyes.

In myopia a partial correction of the error of one eye while the full correction for the associated eye is being made with the retinoscop , relieves the ocular strain that may occur if one eye is occluded during the examination of the other, or only one eye is corrected at a time. A very desirable condition if the person is of a nervous temperament.

If the light beam from the retinoscope is so directed upon the eye that the area of illumination on the retina covers the yellow spot (macula), it may prove annoying to the patient and further contract the pupils, therefore, direct the patient not to look at the retinoscopic mirror, but to either side of the operator's head or just over his head. A desirable position for the patient to assume is to have him face the operator squarely, with the head inclined slightly downward, and his vision fixed upon some object just over and behind the head of the operator.

This position throws the area of illumination upon a portion of the retina sufficiently near to the centre of perception (the macula) to obtain the best results without causing the patient any discomfort.

The retinoscopic examination should be conducted as speedily as is consistent with accurate work, if it is too prolonged it will prove as annoying as a lengthy subjective test.

Nervous patients often ask if the strong light from the retinoscope will harm the eye, They may be reassured by telling them that it is harmless, the effect of the glare passing quickly away after the examination.

A retinoscope in which the peep-hole is drilled through the glass frequently shows annoying reflections from the edge of the hole; it causes a peculiar spider web effect of light that interferes with the view of the reflex. In selecting an instrument care should be exercised to see that this defect does not exist. Some instruments do not have the hole in the glass, the peep-hole being made through the silver backing of the mirror only, this obviates the above defect but does not permit as much of the emergent light to reach the eye of the observer as where the glass is drilled.

As the reversal point is reached, particularly in cases of high myopia and high hypermetropia, or when the pupils are large, it may be observed that in the central portion of the pupil the reflex will appear to be choked, while in the peripheral portions of the pupil there may still appear to be movement. If a lens be imposed that will choke the peripheral portions, movement may still occur in the central portion of the pupil.

This is due to the spherical abberation of the eye, and interferes with the retinoscopic estimate of the error to more or less degree. As the central portion of the pupil is most nearly concerned in vision, base the estimate upon the lens required to choke the reflex in the centre of the pupil.

If the reflex shows an irregular movement in the pupil, the light area in the pupil being broken up into little patches of varying brilliancy which move in different directions as a transit of the light beam is made, a condition of irregular refraction in the refracting system of the eye is indicated. This seriously impairs the value of the retinoscopic examination. In such cases it will be usual to find that the visual acuity is sub-normal and incapable of being raised to normal with any lens. Conical cornea, corneal scars, etc. cause this condition.

In younger persons the pupils are apt to be large, this exposes a large area of the refracting system of the eye. As nearly all eyes possess a little astigmatic error, as the reversal point is reached in the retinoscopic examination, this astigmatism becomes manifest, it may be regular or irregular and may prove confusing to the operator. It

may happen that a weak cylinder seems indicated at a certain axis, yet on proving the estimate subjectively, the operator may find that the patient demands that the axis be at the opposite position that was estimated with the retinoscope. Some have condemned the retinoscope for this apparent failure but it is the operator who is to blame, not the instrument. This can only occur with weak cylinders and will not occur when the operator acquires skill and experience.

The introduction of the luminous retinoscope into the practice of retinoscopy has widened the field of the retinoscopic test; it makes it possible to obtain a reflex of sufficient brilliancy under all conditions for the observer to see it. If a reflex may be obtained that it is possible for the refractionist to see, he will be enabled to apply the test.

This form of instrument is a great help to the student, the author finding it most valuable in his work as an instructor of ocular refraction.

In this book the student will doubtless note the absence of any instructions regarding Subjective work with the Test Case. This must not be construed to mean that the author undervalues this work, nor overestimates the value of Objective methods. In correcting ocular errors of refraction the two methods should be employed in every case, (excepting those cases of young children, illiterates, etc.) each serving to verify the findings of the other and thus tending toward greater accuracy.

The demand for accurately adapted lenses for the eye is growing, and greater exactitude is required of the refractionist. In justice to his patient, as well as for his own material benefit, all methods of value should be practiced. As stated in the beginning of this work, the author believes that Retinoscopy is the most valuable of all methods and should be given preference, but its findings should be checked up by subjective work with the test case. This statement must not be taken as an admission of inaccuracy of the retinoscopic findings; their value depends upon the skill of the operator.

So much has been written of Subjective work that it is not deemed necessary to include it in this book.

GLOSSARY OF TECHNICAL TERMS

The following list includes all the technical terms used in this work, as well as others in frequent use in optical literature:

ABDUCTION, power of. The term used to describe the effort required to unite two images created by placing a prism base inward before the eyes. The strongest prism so overcome is the measure of the strength of the external recti. The normal measure of strength is 7° to 8°.

ABERRATION (*A wandering away*). In optics used to describe the deviation of light rays. See Spherical Aberration and Chromatic Aberration.

ACCOMMODATION. The function by which the eye is capable of increasing its refraction, thus focusing for far and near.

ACHROMATIC (*Without color*). The term used to describe a lens corrected for chromatic aberration.

ACHROMATOPSIA. Total color-blindness.

ACUITY OF VISION. Measure of sensibility of sight.

ADDUCTION, power of. The effort required to fuse two images created by placing a prism base outward before the eyes. The strongest prism so overcome is the measure of strength of the internal recti. The average normal strength is 18° to 24°.

AMBLYOPIA. Sub-normal visual acuity; it may be congenital, or an acquired condition.

AMETROPIA. Abnormal conditions of refraction; all errors of refraction are classed under this one head.

AMPLITUDE OF ACCOMMODATION. The measure of the power of accommodation, usually expressed in dioptres. It varies according to age.

ANISOMETROPIA. A marked difference in the refraction of two associated eyes.

APERTURE of a lens or mirror. The diameter of a lens or mirror available for optical purposes of refraction or reflection.

APHAKIA. The condition of the eye when the crystalline lens has been removed, as after operation for cataract.

AQUEOUS. The watery humor of the eye.

ARCUS SENILIS (*A bow of the aged*). A white ring that appears around the outer edge of the cornea in elderly people.

ASTHENOPIA (*Weakness*). A muscular weakness. It is of two classes: Accommodative Asthenopia, weakness of the ciliary muscles; Muscular Asthenopia, weakness of the motor muscles. It is manifest in ocular distress in reading and close point application.

ASTIGMATISM. Descriptive of condition of unequal refraction in various meridians of the eye, and requiring a cylinder lens for its correction.

ATROPHY (*Wasting*). A condition brought about by lack of proper nourishment to the eye, caused by poison, etc. See Toxic Amblyopia.

AXIS. An imaginary line about which a body turns.

BALANCE OF THE EXTRA-OCULAR MUSCLES. Proper comparative strength of the motor muscles.

BINOCULAR VISION. Single perception with two eyes.

BLIND SPOT. The point of no vision on the retina. Where the optic nerve pierces the retina.
CANTHUS. The angle where the eyelids meet; in each eye there is the inner and outer canthus.
CATARACT. An opacity of the crystalline lens, usually acquired in old age; sometimes congenital.
CHOKED REFLEX. The appearance of the retinal reflex in retinoscopy when the point of reversal is reached, no movement being seen.
CHOROID. The middle coat of the eye.
CHOROIDITIS. Inflammation of the choroid.
CHROMATIC ABERRATION. Dispersion of light due to unequal deviation of the rays by refraction.
COLOBOMA. A rent or fissure of the membranes of the eye.
CONCOMITANT SQUINT. That condition in which one eye deviates from the point of fixation, yet retains its visual power; if the dominant eye be covered, the deviating eye will fix the object seen.
CONGENITAL. Existing at birth.
CONJUNCTIVA. Mucous membrane lining the eyelids and extending continuously over the exposed portion of the eyeball.
CONJUNCTIVITIS. Inflammation of the conjunctiva.
CONJUGATE FOCI. Two points so related that rays of light emanating from one and refracted by a convex spherical lens focus at the other. Their positions are interchangeable.
CONVERGENCE. The power by which the eyes are turned inward to observe an object at a near point.
CORNEA. The outer, transparent portion of the eye.
COVER TEST. See Test.
CRYSTALLINE LENS. The double convex lens of the eye forming part of the refracting system of the eye, and capable of increasing its power of refraction. Part of the apparatus of accommodation.
CYCLITIS. Inflammation of the ciliaries.
CYCLOPLEGIA. Paralysis of the ciliary muscles.
DIOPTRE. The unit of measure for lenses based upon the metric system. A lens having a focus of approximately 40 inches.
DIPLOPIA. Double vision.
DISK, THE. Sometimes used to designate the head of the optic nerve as seen with the ophthalmoscope.
EMMETROPIA. That condition of the eye in which normal conditions of refraction exist.
ENUCLEATION. A removal of the eye.
EPIPHORA. Excessive flow of tears, watering of the eye. Usually caused by a partial or complete stoppage of the tear duct.
ERRORS OF REFRACTION. Abnormal conditions of refraction in the eye.
ESOPHORIA. A tendency of the visual line inward.
ESOTROPIA. A turning inward of the eye.
EXOPHORIA. A tendency of the eye to turn outward.
EXOTROPIA. A turning of the eye outward.
EXTRA-OCULAR MUSCLES. The motor muscles.
FAR POINT. The point from which the eye in a state of rest is adapted to receive and focus rays of light upon its retina. Punctum Remotum.
FIELD OF VISION. That portion of space perceptible to the eye at one time; that is,

without its shifting the point of fixation.

FOCUS (*A fire place*). The point at which rays of light meet after refraction by a lens, or reflection by a mirror.

FORAMEN, OPTIC. Opening into the orbital cavity through which the optic nerve and central artery reach the eye.

FOVEA CENTRALIS. A small depression in the macula, where the retina is most sensitive to vision. Where the line of vision meets the retina under normal conditions without an effort.

FUNDUS. The eye ground. Seen with the ophthalmoscope. It includes the optic nerve, arteries, etc.

GENERIC COMPOUNDS. Lenses having spherical and cylindrical curvature of the same species; that is, both convex, or both concave. Contra-generic compounds have one surface convex, the other concave.

GLAUCOMA. A disease of the eye in which there is an abnormal increase in the contents of the globe, causing excessive tension. The pupil is sluggish and assumes a sea green tint; hence the name.

GRANULATED EYELIDS. Granular conjunctivitis.

HEMERALOPIA. Day vision, or night blindness.

HETEROPHORIA. An imbalance of the motor muscles of the eye. A tendency of the visual line of one eye to deviation from the other.

HETEROTROPIA. An actual deviation of the visual lines from parallelism.

HOMONYMOUS DIPLOPIA. Double vision in which the two images occupy the same relative positions regardless of the direction of the look.

HYPERMETROPIA (*The far-sighted eye*). The hypermetropic eye possesses equal refraction in every meridian, but the retina is situated between the refracting system and its principal focus.

HYPERPHORIA. A tendency of deviation of the visual line of one eye above the other.

HYPERTROPIA. A deviation of the visual line of one eye above the other.

ILLUMINATED BODIES. Those that receive light from other bodies.

IMAGE, OPTICAL. An appearance of an object created by refraction or reflection.

INDEX OF REFRACTION. The relative resistance offered to the passage of light rays by various transparent media as compared to that of air.

INFERIOR RECTI. The motor muscles that give the eye a downward direction.

INTERNAL RECTI. The motor muscles that operate to turn the eyes inward.

IRIDECTOMY. The cutting away of a portion of the iris. Performed in glaucoma, cataract operations, etc.

IRIS. A circular membrane that acts as a diaphragm to regulate the amount of light that enters the eye through the pupil. That which gives to the eye its "color."

IRIS SHADOW. The test for maturity, or ripened cataract; created by oblique illumination.

IRITIS. Inflammation of the iris.

JAEGER'S TEST TYPE. The standard type for close-point.

KERATITIS. Inflammation of the cornea.

LENS. An optical instrument for the regular refraction of light according to system.

LIGHT. A form of energy.

LIGHT AREA ON THE FACE. The term used to designate the light upon the face when the beam of light from the retinoscope is directed upon the eye under observation.

LIGHT AREA IN THE PUPIL. The light seen in the pupil of an eye under observation with the retinoscope, caused by the reflex from the retina. Its character and relative movement indicate the refraction of the eye.

LUMINOUS BODIES. Those sources of direct light, as the sun, a lighted candle, etc.

LUMINOUS PUPIL. The appearance of the pupil under observation with the retinoscope.

MACULA LUTEA. The "yellow spot" or region of greatest sensitiveness of the retina.

MADDOX ROD. An optical device to determine the tendency of the visual lines.

MEDIA. The refracting humors of the eye.

MERIDIAN. A great circle that divides the sphere into two equal hemispheres.

MIOSIS. An abnormal pupil contraction.

MIRROR. An instrument of regular reflection, thus capable of creating images.

MOTOR MUSCLES. The muscles that control the movements of the eyes. The Recti.

MYDRIASIS. An abnormal dilation of the pupil.

MYDRIATIC. A drug that acts to dilate the pupil.

MYOPIA. An eye that possesses equal refraction in every meridian, but the retina is situated beyond the principal focus of the refracting system.

MYOTICS. A drug that contracts the pupil.

NEAR POINT. The closest point to the eye of distinct perception, usually measured by Jaeger's test type. Punctum Proximum.

NERVE, OPTIC. The nerve that transmits retinal sensations to the centres of perception in the brain, there to be translated into sight.

NEURITIS, OPTIC. Inflammation of the optic nerve.

NEUTRALIZING. Destroying power. The term used to designate the process of determining the power of an unknown lens.

NYCTALOPIA. Night vision, or day blindness. A term used to describe an improvement in visual acuity in subdued light caused by a dilation of the pupil. A condition noted in Optic Atrophy and Toxic Amblyopia.

NYSTAGMUS. An involuntary oscillating movement of the eyes. A condition frequent in albinism.

OBJECTIVE METHODS. Methods of estimating the refraction of an eye without the assistance of the patient by direct observations of the operator. The most important objective methods are Ophthalmoscopy, Retinoscopy and Ophthalmometry.

OBLIQUE ILLUMINATION. A method of focusing light obliquely upon the cornea. Used in examination of the cornea for opacities, scars, etc.; also to ascertain progress of cataract development.

OCULAR REFRACTION. The science treating of the optical conditions of the eye, the estimation of its errors of refraction, and their connection with lenses for the eye.

OPACITIES. Obstructions to the passage of light through the eye, usually located on the cornea or in the crystalline lens. Cataract causes an opacity of the lens. Opacities of the cornea are frequently traceable to inflammation.

OPAQUE. Impervious to light.

OPHTHALMOMETER. An instrument for measuring the corneal curvatures of the eye to locate corneal astigmatism.

OPHTHALMOSCOPE. An instrument for examination of the interior of the eye. Devised by Helmholtz.

OPTICAL CORRECTIONS. Lenses that change the direction of light rays entering the eyes to such direction as the eyes are adapted to receive and focus them upon the retina. Creating artificially emmetropic conditions when ametropic exist.

OPTICAL IMAGE. See Image.

OPTIC ATROPHY. Partial or total loss of sight due to an impairment of the

Optic Axis. An imaginary line drawn from the macula lutea through the optical centre of the refracting system of the eye to the point of fixation.

Optic Disk. The head of the optic nerve seen with the ophthalmoscope.

Optic Nerve. See Nerve.

Optic Neuritis. Inflammation of the optic nerve.

Optometer. An instrument to measure the refraction of the eye.

Orbit. The bony cavity in the skull that contains the eye.

Orthophoria. A normal balance between the motor muscles.

Parallax. The difference of direction of a body as seen from two different positions.

Paralysis. Loss of power of motion in a muscle.

Pathologic. Pertaining to diseased conditions.

Penumbra. A partial shadow.

Perception, Centres of. Those portions of the brain that are the sources of the optic nerves.

Perimeter. An instrument for measuring the field of vision.

Periphery. The edge of a circular body.

Periscopic. A form of lens having one surface concave, the other convex.

Phorometer. An instrument for measuring the strength of the recti.

Photophobia. Intolerance to light.

Pin-Hole Disk. A blank disk pierced with a small round hole, used to determine if sub-normal acuity of vision is due to an error of refraction.

Point of Fixation. The point to which the look is directed.

Point of Reversal. In Retinoscopy the term is used to designate the point between an erect and an inverted image, where the change from one to the other occurs. Where convergent rays change to divergent rays. The myopic far-point in Retinoscopy, where the movement of the reflex appears choked.

Presbyopia. A physical change that occurs in the eye, progressing according to age. A loss of the power of accommodation.

Principal Focus. The point where parallel rays of light meet after refraction by a convex spherical lens.

Prism. An optical instrument of refraction having two plane surfaces inclined toward each other; light rays passing through a prism are bent toward the thicker portion, called the base.

Prism-Dioptre. The unit of measure for prism value, devised by Prentice. A prism that deviates a ray of light one centimeter at one metre distance.

Progressive Myopia. Myopia with tendency to increase.

Protractor Scale. A device for indicating the location of the axis of a cylinder lens.

Ptosis. Drooping of the upper eyelid.

Pterygium. A wedge shape growth of membrane on the conjunctiva, with its point toward the cornea. Usually occurs with sailors and others exposed to the cutting winds.

Punctum Proximum. See Near-Point.

Punctum Remotum. See Far-Point.

Pupil. The circular opening in the iris that admits light to the eye.

Radiant Point. A point from which light diverges.

Range of Accommodation. The distance between the near-point and far-point of the eye.

Reflection (*Bending backward.*) In optics, applied to the change of direction of light rays incident upon a surface that is not transparent. See Mirror.

Refracting Media. See Media.

Refracting System. A lens, or combination of lenses, for the creation of optical images.

Refraction (*A bending*). Applied to the change of direction of light rays passing from one medium into another of different density.

Retina. The inner nervous coat of the eye that is sensitive to light impulses, thus registering the optical images formed upon it by the refracting system of the eye.

Retinal Reflex. A term used in Retinoscopy to designate the light reflected from the retina and creating the light in the pupil.

Retinitis. Inflammation of the retina.

Retinoscope. An instrument for the practice of the objective test called Retinoscopy. By its use a beam of light is directed into the eye under observation, creating a reflection from the retina. See Retinoscopy.

Retinoscopy. The name given to the objective method of estimating the refraction of the eye by creating a reflex of light from the retina. The manner in which these reflected rays emerge from the eye indicate its refraction. Also called Skiascopy and The Shadow Test.

Reversal Point. See Point of Reversal.

Rotation of the Mirror. A term used in Retinoscopy to indicate the movement of the mirror to create a movement of the light area.

Scissors Movement. A peculiar movement of the retinal reflex, resembling the opening and shutting of a pair of scissors. It indicates a condition of irregular astigmatism.

Sclera. The outer coat of the eye. The white of the eye.

Scleritis. Inflammation of the sclera.

Scotoma. A spot in the visual field.

Shadow Test. See Retinoscopy.

Skiascopy. See Retinoscopy.

Snellen's Test Type. The standard for measuring and recording visual acuity.

Spectrum. The effect created when white light is separated into its component colors by a prism.

Squint. See Strabismus.

Staphyloma. A bulging of the ocular coats; it usually occurs at the weakest portion, the back of the globe, and is then called Posterior Staphyloma. A common sequence of myopia.

Stenopaic Disk. A blank disk having a straight, narrow slit, used to locate the principal meridians of an astigmatic eye.

Strabismus. A deviation of one eye from the normal visual angle. Convergent Strabismus, an inward squint, frequently traceable to hypermetropia.

Stye. A small boil upon the eyelid. Usually an evidence of eye strain.

Subjective Methods. Methods of estimating the refraction of the eye by asking the ability to recognize certain forms and test types.

Sursumduction. The power required to overcome a diplopia created by placing a prism base down before the right eye or base up before the left is called Right Sursumduction; base down before the left or base up before the right is Left Sursumduction. A normal power of sursumduction is 2 to 3.

Tenotomy. The operation of cutting the motor muscles to correct squint or relieve muscular imbalance.

Tension. The hardness of the eyeball.

Test, Cover. A test for muscular imbalance by covering one eye and observing its movement when uncovered; the point of fixation being established.

TOXIC AMBLYOPIA. Amblyopia caused by a poison, a common cause being excessive use of tobacco or liquor or both.

TRANSIT. A passing across. A term used in Retinoscopy to indicate movement of the light area.

TRANSLUCENT. A condition between transparent and opaque. Permitting partial transmission of light.

TRANSPARENT. Having the property of permitting rays of light to pass through, so that objects may be seen through a transparent object.

TRANSPOSITION. In optics a change of form without altering the optical value.

TUNICS. The ocular coats.

UMBRA. A shadow.

VISUAL ACUITY. The measure of sensibility of the eye and the power of perception.

VITREOUS. The jelly-like humor of the eye.

WORKING DISTANCE IN RETINOSCOPY. The distance of the operator from the eye under observation when the reversal point is located.

YELLOW SPOT. See Macula Lutea.

INDEX OF SUBJECTS